# E-Fields for Cryogenic nEDM

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# Introduction

Most recent neutron edm experiments carry out magnetic resonance on polarised ultracold neutrons (UCN) stored at Room Temperature (RT). The sensitivity to an electric dipole moment is directly proportional to the strength of the E-field applied across the resonance, or Ramsey cell. To date, the maximum fields obtained in such RT experiments have been ~10kV/cm.

# **3** Dielectric Breakdown in Liquid <sup>4</sup>He under SVP

A number of experiments have shown that the breakdown voltage, Vbd, in liquid 4He under SVP decreases significantly as the temperature, and hence pressure, are reduced below 4.2K. Our data in Fig. 2 were taken in a pumped bath cryostat and show a reduction in Vbd by a factor ~3 down to about 1.7K, at which point the hydrostatic pressure equals the SVP.



# **CryoEDM** at ILL

In the CryoEDM experiment at ILL, the UCN are both produced and then measured in superfluid <sup>4</sup>He. Given the known high dielectric strength of liquid <sup>4</sup>He, there has been an expectation that larger E-fields than used at RT could be used in this and similar cryogenic experiments. However, to prevent thermal up-scattering of UCN, the helium needs to be held at ~0.6K, at which point the SVP is ~10<sup>-3</sup> mbar.

IFigure 1 shows the double Ramsey cell currently in use at CryoEDM. The 250mm diameter Be electrodes are separated by a 45mm BeO spacer and has been run at 0.6K under SVP at +10kV/cm and -13kV/cm. In the present arrangement the voltage limits of ~50-60kV are due to the feedthrough.



# Pressure-Dependent Breakdown at Constant T

Figure 3 shows the general form of Vbd(P) data taken at constant T in the pressure cell depicted in Fig. 4. The electrode diameters are 32mm and the separation 1.27mm. Figure 5 summarises the 1600 data points taken on a fixed electrode geometry in 12 separate cooldowns at temperatures down to 1.7K. There is good evidence that each breakdown event occurs at a different point on the electrode surface and that the 4.2K SVP Vbd calibration point taken at the start of each run only decreased for the last three runs. The data sets have hence been normalized to 50kV at 1600mbar.

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### **Proposal to Explain V<sub>bd</sub>(P,T)**

Once thermalised, ions and electrons in liquid 4He exhibit extremely low mobilities due to the formation of a solid He "snowball" around the ion and the formation of a "bubble" around the electron. This latter description is slightly misleading since it does not contain any gas – the term "exclusion void" might be more appropriate. Both of these entities can easily lose energy to low level excitations in the 4He and this leads to the high dielectric strength. Nevertheless, dielectric breakdown does occur in liquid 4He, essentially through an ionized gas "streamer" and it is proposed that this starts from an initial (gas) bubble which is formed at the surface of an electrode. If this "seed" bubble grows, then the gas within it is expected to become ionized.





The initial rapid increase in V<sub>bd</sub> in our two-regime behaviour is thus attributed to the increased pressure suppressing the growth of the "seed" bubble. However, due to the differences in dielectric constant between ionized gas inside the bubble and the liquid, there are electrostrictive forces tending to elongate the bubble. This elongation has been sho wn to increases catastrophically above a given value of E-field [1] and we tentatively identify this onset with the change in regime of  $V_{bd}(P)$ . The absolute onset field, elongation calculated with no adjustable parameters, agrees with our measured value within a factor of ~4, as shown in Fig. 6.





The data all appear to show a two-regime behaviour at all temperatures, with a rapid, approximately linear increase in Vbd up to ~120mbar above SVP, followed by a much slower linear increase. Later measurements confirm this behaviour at 1.3K, or 0.6 T $\lambda$ .

#### Maximum Attainable E-field in a Cryogenic Expt?

Figure 7 opposite summarises the values of E-fields attained in liquid 4He from the data reported here (blue and red circles, by Long et al [2] (blue and red squares) and at CryoEDM (blue triangle). In the latter case the electrodes were separated by a BeO spacer, as shown in Fig. 1. It is evident that fields in excess of 100kV/cm could be maintained across the liquid at 4.2K in realistic nEDM Ramsey cells and our data suggests that this could also apply at 0.6K, provided that the system is pressurized to ~1bar. However, it is important to note that this prediction takes no account of the potential problems associated with the necessary insulating spacers between the electrodes, and that these are expected to dominate at some point.



### **Future Plans for CryoEDM**

On the basis of the work reported here, it is planned to modify CryoEDM to enable mild pressurization of the 4He liquid and to uprate the feedthrough and HV delivery system with the aim of reaching fields of 30kV at ~150kV by 2015. The inverted red triangle in Fig. 7 is this value and is a prediction.

[1] Garton and Krasucki, Proc Roy Soc A280 211 (1964)[2] Long et al,

