Experiment 1095

Measurement of the London Penetration Depth, in $NbSe_2$ using Low Energy Polarized ^{8}Li.

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A fundamental property of any superconductor is the Meissner effect, whereby an external magnetic field is expelled below T_c. This is only strictly true deep inside the sample since, close to the surface, the London model predicts an exponential decay of the magnetic field where the decay length is called the London penetration depth (λ_L). Along with the coherence length (ξ), λ_L is one of the two fundamental length scales in any superconductor. The absolute value of λ_L along with its behavior as a function of temperature and magnetic field is a sensitive probe of the superconducting state; i.e. the nature of the electron pairing and the elementary excitations from the condensate. Few experimental methods are capable of determining a precise value for λ_L. For example, in most superconductors, there are a wide range of published values. The reason for this is that most methods are fraught with systematic errors. Only μSR can be applied to a wide range of materials but conventional μSR can only be applied to the vortex state.

In this experiment, we are using the technique of low energy β detected NMR to investigate the Meissner state of superconductors and in particular, to measure the absolute value of the λ_L. The beam energy is used to control the mean depth of implantation into the sample, which is on the same length scale as λ_L. Both the spin relaxation rate and the resonance spectrum depend on the local magnetic field and thus are sensitive to λ_L. However, the spin relaxation rate is much easier to measure, so we use this to monitor the local magnetic field near the surface. The technique should be applicable to most superconductors but as a first example we have chosen $NbSe_2$.

The ^{8}Li nuclear spin relaxation rate $1/T_1$ in $NbSe_2$ was investigated as a function of magnetic field above and below the superconducting transition at T_c=7.0K. In low field, $1/T_1$ is determined primarily by low frequency fluctuations of the host Nb nuclear spins, which are characterized by an exponential correlation time τ_c. Typical raw data in the normal state at 8 K are shown in Fig. 1. The data is taken by delivering a long (4s) pulse of ^{8}Li and measuring the beta decay asymmetry (which is proportional to the polarization) as a function of time during and after the pulse. The fitting function is generated by convoluting the spin relaxation function with a square pulse shape. This complicates the fitting function but one obtains much higher statistics than with a conventional short pulse. The field dependence of the spin relaxation rate is shown in Fig. 2 and fits well to a Lorentzian as expected for an exponential correlation time. Given this, one expects the relaxation rate to increase below T_c due to the Meissner effect. This is confirmed by the measured temperature dependence of $1/T_1$ (open diamonds in Fig. 3). In particular note the sharp upturn in $1/T_1$ below T_c. There is also a slight temperature dependence to $1/T_1$ above T_c which is attributed to Korringa relaxation of the host nuclear spins (i.e. spin-flip scattering of electrons at the Fermi surface off the nuclear spins). We have shown previously that the direct Korringa relaxation of the ^{8}Li is negligibly small at this temperature. The temperature dependence of τ_c was determined separately from measurements in the vortex state (see solid circles in Fig. 3). These measurements were taken in a much higher magnetic field applied perpendicular to the surface where the sample is in the vortex state and then scaled up to align with the Normal state data at 8K. Recall the average field is almost independent of temperature in the vortex state, so the observed T dependence of $1/T_1$ is attributed solely to changes in τ_c. Note the small bump below T_c for $1/T_1$ in the vortex state which we attribute to the Hebel-Slichter peak in the Niobium $\frac{1}{T_1}$.

Finally, using a calculated implantation profile, assuming an exponential field distribution, and taking into account the temperature dependence of τ_c, one can extract the absolute value of the London penetration depth in the Meissner state. The temperature dependence of λ_L is shown in Fig.4. These results confirm low energy β-NMR can be used to measure the absolute value of λ_L in a superconductor. In addition, the experiment has shown that the spin relaxation rate of the ^{8}Li in low fields is a sensitive monitor of the host nuclear spin dynamics which is also of interest in studies of superconductivity.

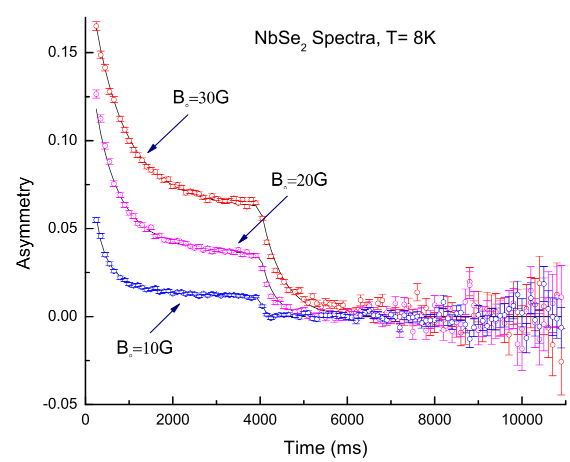

Fig. 1. Time differential spectra at various magnetic fields

in the normal state of $NbSe_2$ at 8K. The data were taken using a 4s long pulse method.

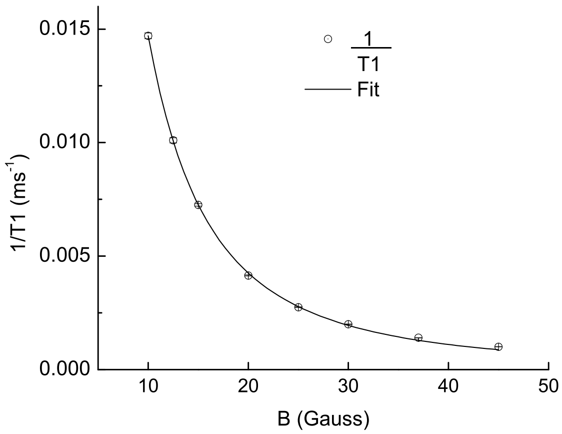

Fig. 2. Magnetic field dependence of the ^{8}Li spin relaxation rate in the normal state of $NbSe_2$ at 8K. The curve is a fit to a simple Lorentzian function.

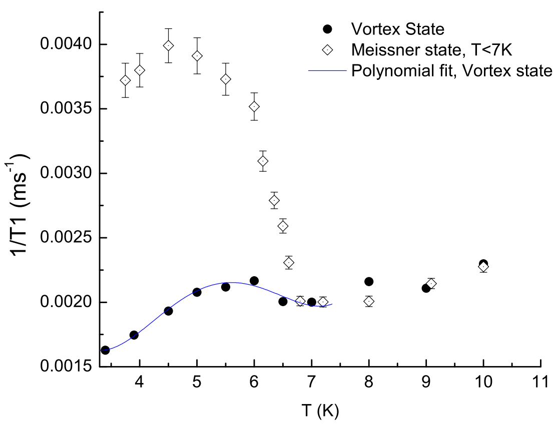

Fig. 2. Temperature dependence of the spin relaxation rate of ^{8}Li in $NbSe_2$. The open diamonds are from data taken with the magnetic field of 30G applied parallel to the surface so the sample remains in the Meissner state. The filled circles are derived from measurements in the vortex state where the magnetic field is applied perpendicular to the surface.

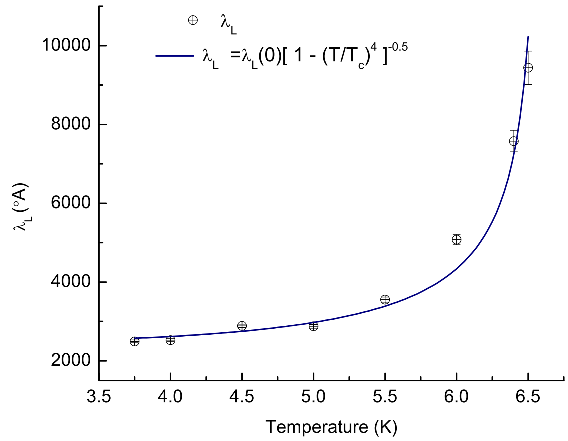

Fig. 2. London penetration depth as a function of temperature.

Publications:

1. Masrur Hossain, T.A. Keeler, Z. Salman, K.H. Chow, G.D. Morris, W.A. MacFarlane, T. Parolin, H. Saadaoui, D. Wang, R.F. Kiefl, *Meissner State of $NbSe_2$ Studied with Low Energy β-NMR*, in preparation (2007).

2. D. Wang, M.D. Hossain, Z. Salman, D. Arseneau, K.H. Chow, S. Daviel, T.A. Keeler, R.F. Kiefl, S.R. Kreitzman, C.D.P. Levy, G.D. Morris, R.I. Miller, W.A. MacFarlane, T.J. Parolin, H. Saadaoui, *β-Detected NMR of ^{8}Li in the Normal State of $2H-NbSe_2$*, Physica B, **374-375**, 239-242 (2006).

Theses:

Measurement of the London Penetration Depth in the Meissner State of $NbSe_2$ using Low Energy Polarized ^{8}Li, Md Masrur Hossain, M.Sc., Department of Physics and Astronomy, UBC.