Experiment 1042

β-NMR Investigation of Finite Size Effects in Metallic Thin Films and Nanoparticle Arrays

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As part of our ongoing study of finite size effects in thin metallic films, we have recently focussed our attention on the particularly interesting case of Palladium, a transition metal intrinsically close to a ferromagnetic instability.

The technique of β-NMR is well suited for the study of thin films; offering the potential to gain depth-resolved information that very few other spectroscopic techniques can, especially conventional NMR. Earlier results from a sample of Pd foil showed unusually large Knight shifts (K, a key quantity in the NMR of metals) for the implanted ^{8}Li. A follow-up study using a 100 nm film on $SrTiO_3$ confirmed that the large K is intrinsic to the Pd host. Before proceeding with further detailed studies of thinner samples, the results from this film are themselves intriguing as measurements of the local susceptibility around dilute, non-magnetic impurities in bulk Pd.

The incident beam was electrostatically decelerated to 11 keV for these measurements to maximize the number of ions stopping in the Pd. Two overlapping signals are seen for Li in Pd; their resonance frequencies both decrease by a similar amount as the temperature is lowered. The reference frequency used to compute K was determined from the known K of Li stopping in the Au capping layer (10 nm) that was deposited *in situ* onto the Pd film. Panel (a) of Fig. 1 displays the average K for the Li signals as a function of temperature in an external field of 4.1 T (points). The trend in $K_{\rm avg}$ with T is similar to what was seen in the 12.5 micron foil. K is assumed to be dominated by the local magnetic susceptibility at the Li. If this susceptibility were the same as that for bulk Pd, K_{avg} should scale with χ_{Pd} for all T. This appears to be the case above $\approx$ 100 K as indicated by the solid line in (a) obtained from the linear fit of this region shown in the inset. Below this point, χ_{Pd} is known to decrease, while K_{avg} is seen to increase further. This low-T deviation can be taken as a measure of the local response of the Pd host to the *isolated* defect of the implanted Li^+ (the concentration of Li here is only $\sim$ 1 in 10^{11}). This response can now be compared with detailed theoretical calculations based, for example, on the scattering of the host Pd spin fluctuations from the defect.

The spin-lattice relaxation T_1^{-1} for the Li was measured in the foil at 4.1 T and the results shown in (b). It is overall linear as expected for relaxation due to polarized electrons in a metal; however, the deviation at higher T is attributed to Li making a site change. The rates of relaxation are much slower than expected from the large $K_{\rm avg}$. For instance, applying the Korringa relation for K_{avg} = -885 ppm predicts a T_1^{-1} given by the dashed line. In (c) the product $(T_1 T K_{avg})$ is seen to be essentially constant, as has been predicted for a nearly ferromagnetic system. The high-T change in T_1^{-1}, and the low-T increase in $K_{\rm avg}$ discussed are responsible for the small nonlinearity observed.

Preliminary measurements indicate that the shift of ^{8}Li in Pd is strongly dependent on the Pd film thickness for thicknesses below 100 nm. Further measurements are planned to study this remarkable and unexpected finite size effect.

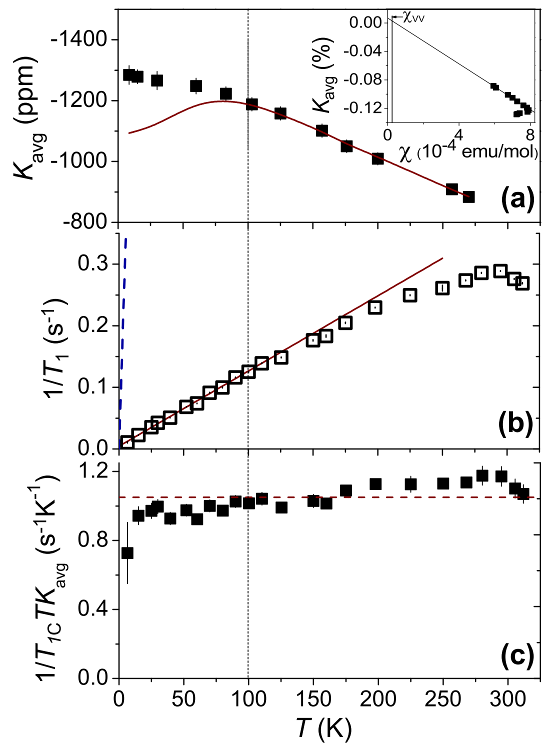

Fig. 1. (a) Knight shift of Li in 100 nm Pd at 4.1 T. The solid line represents the shifts predicted for K_{avg} linear with the bulk susceptibility of Pd for all T (inset). (b) Spin-lattice relaxation rate T_1^{-1} of Li in Pd foil at 4.1 T. (c) The product $T_1 T K_{avg}$ is nearly independent of T as predicted for nearly ferromagnetic material. Some of the $K_{\rm avg}$ have been interpolated/extrapolated from (a).

Publications:

T.J. Parolin, Z. Salman, J. Chakhalian, D. Wang, T.A. Keeler, M.D. Hossain, R.F. Kiefl, K.H. Chow, G.D. Morris, R.I. Miller, and W.A. MacFarlane, *β-NMR of Palladium Foil*, Physica B **374-5**, 419 (2006).

T.J. Parolin, Z. Salman, J. Chakhalian, Q. Song, K.H. Chow, M.D. Hossain, T.A. Keeler, R.F. Kiefl,

S.R. Kreitzman, C.D.P. Levy, R.I. Miller, G.D. Morris, M.R. Pearson, H. Saadaoui, D. Wang, and W.A. MacFarlane, *β-NMR of Isolated Lithium in Nearly Ferromagnetic Palladium*, Phys. Rev. Lett. **98**, 047601 (2007).

Appendix D and Appendix E update: T. J. Parolin (UBC Chemistry), W.A. MacFarlane (UBC Chemistry), Z. Salman (U. Oxford Physics), G.D. Morris (TRIUMF), R.F. Kiefl (UBC Physics/TRIUMF), K.H. Chow (U. Alberta Physics), D. Wang (UBC Physics), M.D. Hossain (UBC Physics), H. Saadaoui (UBC Physics), Q. Song (UBC Physics), M. Smadella (UBC Physics), J. Chakhalian (U. Arkansas Physics).

Status: active.