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PRECESSION OF μ^+ IN SINGLE CRYSTAL NICKEL*

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We have observed long-lived μ^+ precession in single crystal nickel at 300 and 77K. Inhomogeneous local fields which cause rapid depolarization in polycrystalline samples are avoided. Muon precession in a magnetically saturated sample is reported.

In a recent letter [1], Kossler et al. reported the first observation of the precession of positive muons in polycrystalline nickel. We have extended this investigation to single crystal nickel and have enlarged the range of external field and sample temperature over which measurements can be made. This has lead us to a modified interpretation of the data.

Polarized positive muons are trapped interstitially in a nickel target situated in a transverse magnetic field B_{ext}. The muon Larmor precession in the local field is monitored via the precessing angular distribution of positrons from the anisotropic μ-decay. This allows measurement of the local field B_μ and the depolarization time T_2.

The measured value of B_μ is +1.48 kG at 77K. This field arises predominantly from the Lorentz field $4\pi M/3 = +2.14$ kG. Since the dipole fields from Ni cores cancel by symmetry at a cubic interstitial site, the difference of -0.66 kG must come from contact interaction with band electrons. Neutron diffraction studies yield an unperturbed interstitial magnetization $M_{loc} = -0.85 \times 10^{22}\ \mu_B/cm^3$ [2] or -0.079 kG, which implies a contact field of $8\pi M_{loc}/3 = -0.66$ kG. This agreement, although suggestive, must be regarded as fortuitous since the charge of the muon must be screened by band electrons. A detailed calculation should reliably account for B_μ.

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Kossler's group [1] measured B_μ and T_2 as a function of temperature in a polycrystal below saturation. We observed precession below and above saturation in a heated, ellipsoidal, polycrystalline sample, and have also detected long-lived precession in a single crystal at 77K. Kossler saw no precession below 300K.

We interpret the absence of precession in a cold polycrystal to arise from an extremely short T_2 caused by a large inhomogeneous linewidth ΔB. T_2 and ΔB are related by: $\Delta B = 2/\gamma_\mu T_2$, where γ_μ is the muon magneto-mechanical ratio. Figure 1 shows Kossler's values of ΔB and our uncertain polycrystal data at 77 and 300K compared with ^{61}Ni NMR linewidths in polycrystalline nickel from work by Streever and Bennett [3]. That ΔB for muons and NMR are comparable even though the nuclear hyperfine field is 50 times that of the muon implies that ΔB is not due to strains, but to macroscopic field inhomogeneities arising from the fields of randomly oriented crystallites. The upward trend of ΔB in Figure 1 at lower temperatures may be qualitatively understood in terms of an increase in the anisotropy energy with decreasing temperature [4] causing an increase in magnetization inhomogeneity.

This view is supported by our observation of long-lived ($T_2 > 2\mu$sec)[‡] μ^+ precession in a single crystal sample at 300 and 77K. The linewidths inferred ($\Delta B_{77} < 18$G, $\Delta B_{300} < 10$G) are an order of magnitude smaller than Barclay's linewidth from NMR of oriented ^{60}Co nuclei in single crystal nickel [5], and to our knowledge they are the narrowest absolute linewidths yet observed in nickel.

Kossler's ΔB data [1] shows a sharp rise above 550K. Since $B_\mu(T)$ (Fig. 1 [6]) becomes very steep near the Curie temperature T_c, imperfect temperature homogeneity would produce a ΔB which increases as T_c is approached. Kossler's data can be explained with a temperature spread ~ 10K.

With a small ellipsoidal target, we have observed precession in a magnetically saturated sample. We found, in agreement with Kossler, that B_μ is independent of B_{ext} below saturation, while above saturation, B_μ rises linearly with B_{ext} with unit slope. This dependence can be explained through the mechanism of magnetic shielding.

We wish to thank Dr. C. Kittel for helpful discussions and Leal Kanstein and the 184-inch cyclotron crew for technical assistance.

[‡] Only an upper limit for T_2 can be given due to the short muon lifetime (2.2 μsec) and the interference of the precession signal with a 19 MHz background signal arising from the time structure of the cyclotron beam.

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FIGURE CAPTION

Fig. 1. The local field B_μ at the muon site and linewidths ΔB observed in polycrystalline and single crystal nickel by various techniques. The solid curve is from normalized magnetization data in Ni of reference [6].

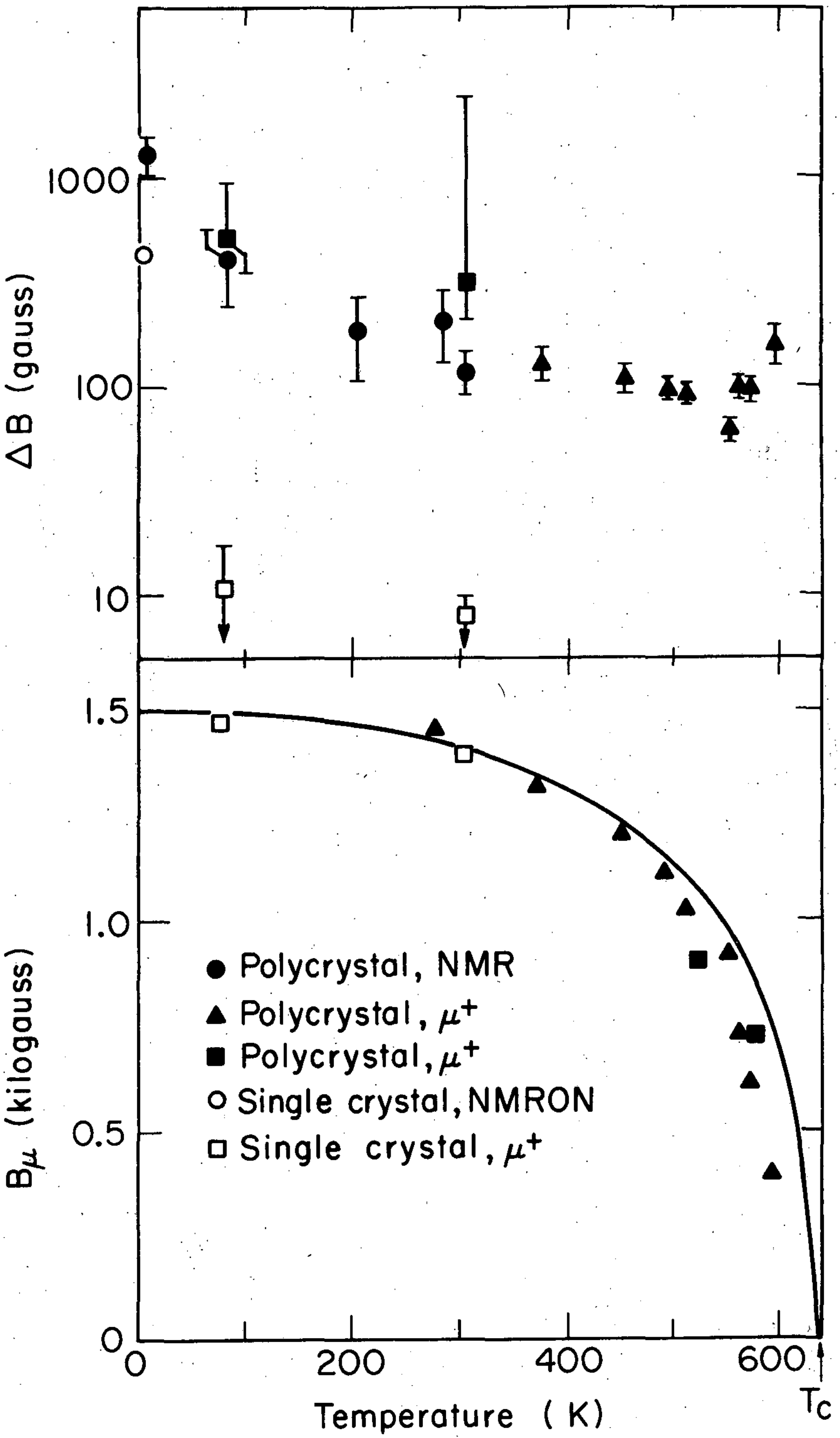

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Fig. 1.

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