Hyperfine Interactions 104 (1997) 281–285

µSR investigation of single crystalline dysprosium

M. Ekström [a], O. Hartmann [a], A. Marelius [a], R. Wäppling [a], E. Schreier [b], S. Henneberger [b], A. Kratzer [b] and G.M. Kalvius [b]

[a] *Department of Physics, University of Uppsala, S-751 21 Uppsala, Sweden*
[b] *Physik Department, Technische Universität München, D-85747 Garching, Germany*

Muon spin rotation (µSR) data on a single crystalline sample of Dy have been obtained as function of temperature and applied hydrostatic pressure. The discontinuity observed in our new data at the phase transition at 85 K strongly suggests that the muons occupy tetrahedral interstitial sites, with a contact field $B_C = -2.5$ T at the lowest temperatures.

Measurements with applied pressures up to 0.8 GPa show that the magnitude of the local fields increases with pressure at 0.3 GPa, and that the muon signal in the antiferromagnetic phase has essentially disappeared at 0.8 GPa.

1. Introduction

The local magnetic field in ferromagnets observed with the muon spin rotation technique contains information about the dipolar field and the contact field at the muon site in the material. In the interstitial sites where muons reside, these contributions can be of similar order of magnitude, and the dipolar contribution can, in several cases, provide the information about which interstitial site the muons occupy.

Among the elemental ferromagnets, muon precession in local fields has been observed in Fe, Ni, Co, Gd, Dy and Er. In the hcp metals Gd and Co, the muons were found to reside at octahedral interstitial sites [1], while in Dy the earlier measurements could not distinguish between the two sites [1,2]. In other (non-magnetic) hcp metals, the muons seem to prefer tetrahedral sites, as in Sc [3].

2. Experimental

The new µSR measurements on Dy were performed at PSI, Switzerland, in a decay muon beam. The samples consisted of 3 pieces cut from a single crystal of Dy. Data were obtained from 10 to 250 K in a closed cycle refrigerator, below 10 K in a 3-He cryostat, and in applied high pressures up to 0.8 GPa in a special high pressure apparatus [4]. All measurements were done in zero applied field, and with the initial muon spin polarization parallel to the crystal c-axis.

3. Results

Precession frequencies and muon site

The muon precession frequencies observed in the ferromagnetic $(T_{\mathrm{c}} = 85\ \mathrm{K})$ and helical antiferromagnetic $(T_{\mathrm{N}} = 180\ \mathrm{K})$ phases are shown in fig. 1. The general behavior of the data follows those of the older measurements of Hofmann et al. [1,2], but deviations are found in the ferromagnetic phase. The accuracy of the data points are limited to typically 0.5 MHz, due to the strong damping of the precession signal $(\lambda = 15{-}25\ \mu\mathrm{s}^{-1})$.

As previously seen, the change in muon frequency when passing the phase transition at 85 K is quite small. The local magnetic field B_{μ} is the sum of contact and dipolar contributions. The change in dipolar fields can be calculated for the different possible sites, and it is found that the tetrahedral site gives rise to a small change, while the octahedral site should be practically unchanged when passing the transition. In contrast to ref. [1], our data show a change in frequency which is in perfect agreement with the calculated values for tetrahedral site, assuming that the dipolar field is opposite to the contact field.

Thus we arrive at the conclusion that muons do occupy tetrahedral sites, and that the hyperfine (contact) field is negative, with approximate value $B_{\mathrm{C}}\ (T = 0) = -2.5$ T. The residual contact field, obtained from the data after subtracting the calculated dipolar field in tetrahedral sites (ref. [1]), is shown in fig. 2.

In the ferromagnetic phase we observe, unexpectedly, that the maximum muon frequency is found around 50 K, showing that the muon field does not quite follow the bulk magnetization. The magnetic structure of Dy below 85 K has been assumed to be simple ferromagnetic, with moments aligned along the b-axis. Recent magnetization measurements suggest however that a small c-axis component develops below $T =$ 4 K [5]. This effect cannot be seen in the muon data where the precession frequency appears practically constant below $T = 10$ K (fig. 1).

Relaxation rates

The relaxation rate of the precessing signals in the magnetic phases appear to be essentially due to inhomogeneous broadening, and no evidence for significant relaxation due to fluctuating environments can be seen in our data. This is of interest for the anti-ferromagnetic phase, where Barsov et al. [6] observed a temperature dependent relaxation rate, increasing towards T_{N}. Those data were analyzed in a model where the diffusional motion of the muon was the origin of the variations in fields, and values

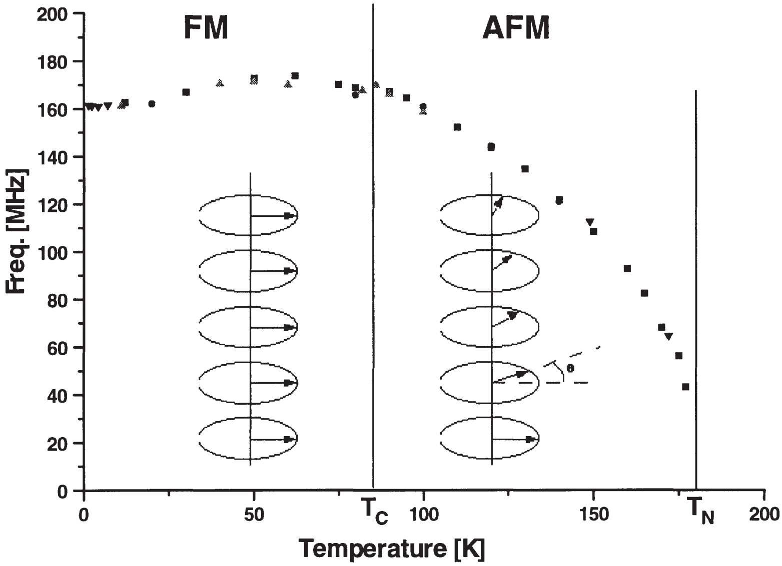

Fig. 1. Observed muon precession frequencies in single crystal Dy. The local magnetic field B_μ is obtained from the relation $f = 135.5\ B_\mu$ [MHz/T].

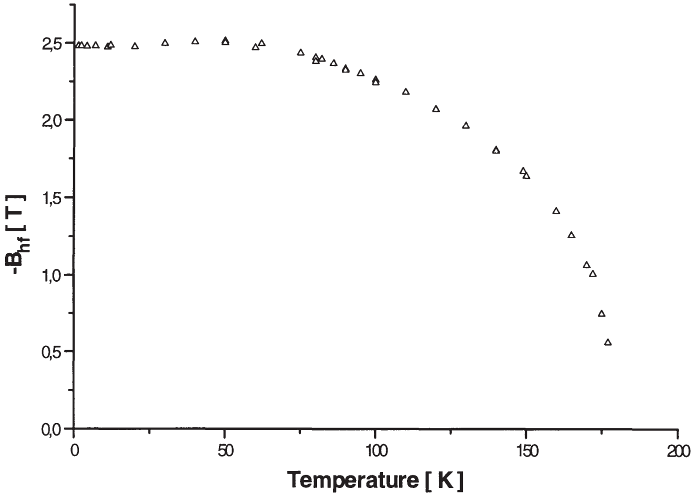

Fig. 2. Derived contact fields as function of temperature in single crystal Dy, assuming muons occupying tetrahedral interstitial sites.

for muon diffusion parameters could be obtained. Unfortunately, we do not observe such changes in the longitudinal depolarization rates in the present experiment.

In the paramagnetic phase, the relaxation rate falls very quickly above T_N to a practically constant value around 3 μs^{-1} (fig. 3). These data are in good agreement with the corresponding data from Barsov et al. [6].

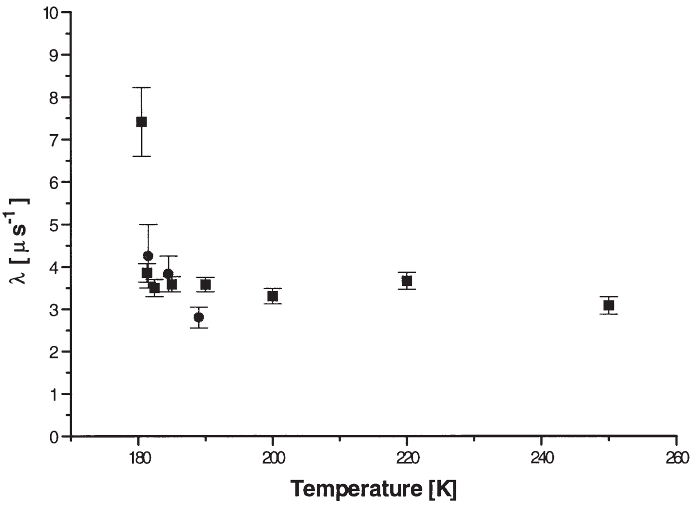

Fig. 3. Zero field relaxation rates for positive muons in Dy above T_N.

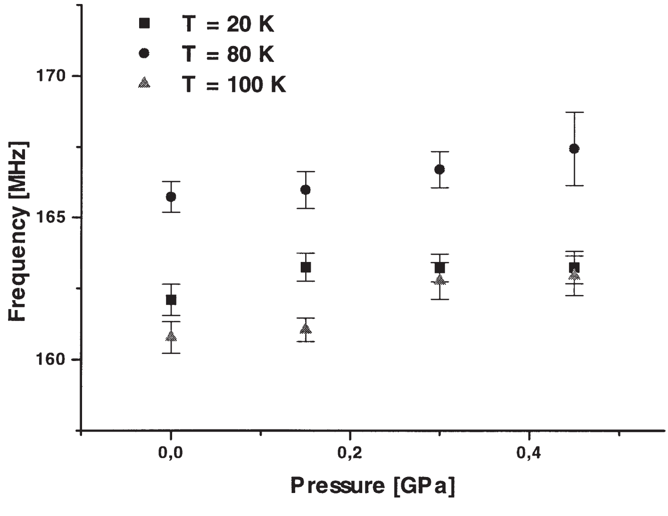

Fig. 4. Dependence of measured precession frequency on applied hydrostatic pressure.

High pressure experiments

Preliminary experiments with applying hydrostatic pressure on Dy have also been performed. The data obtained so far show that at 0.3 GPa the local field increases with pressure, fig. 4. In the antiferromagnetic static the precession signal disappears at higher pressures (0.8 GPa), possibly due to increased inhomogeneous broadening of the precession signal.

References

[1] A.B. Denison, H. Graf, W. Kundig and P.F. Meier, Helv. Phys. Acta 52 (1979) 460.
[2] W. Hofmann et al., Phys. Lett. A 65 (1978) 343.
[3] F.N. Gygax, A. Amato, A. Schenck, I.S. Anderson, J.J. Rush and G. Solt, Hyp. Int. 85 (1994) 73.
[4] A. Kratzer et al., Hyp. Int. 87 (1994) 1055.
[5] F. Willis and N. Ali, J. Phys. Cond. Matter 2 (1990) 8205;
F. Willis and N. Ali, J. Appl. Phys. 69 (1991) 5694;
F. Willis and N. Ali, J. Appl. Phys. 70 (1991) 6548.
[6] S.G. Barsov et al., Sov. Phys. JETP 64 (1986) 174;
S.G. Barsov et al., Hyp. Int. 31 (1986) 255.