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IN NOBLE METALS

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MAGNETIC FIELD DEPENDENCE OF IMPURITY-INDUCED MUON DEPOLARIZATION
IN NOBLE METALS*

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ABSTRACT

We have measured the magnetic-field dependence of the muon depolarization rate up to 5 kOe in AuGd (350 ppm), AgGd (340 ppm) and AgEr (300 ppm). A simple model which includes both dipolar and nearest-neighbor contact interactions between the muon and the magnetic impurity does not fit the data. An axial crystal-field interaction, arising from the electric-field gradient induced by the muon at the site of the impurity, is found to dominate the Hamiltonian, and may have a large effect on the field dependence.

Earlier we reported on measurements of muon diffusion parameters in noble metals doped with magnetic ions.¹⁻⁴ Since the magnetic moments of the host nuclei are insignificant, muon depolarization is caused by the interaction of the μ^+ with the impurity paramagnetic moments and can occur only if the μ^+ diffuses to the vicinity of the impurity sites. By measuring the temperature dependence of the muon depolarization rate, λ , the muon diffusion parameters are then determined. A model² has been employed which accounts for the muon motion through the lattice and

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includes both dipolar and nearest-neighbor contact interactions between the μ^+ and the impurity. For the purpose of determining the diffusion parameters (activation energy and prefactor), detailed knowledge of the nature of the μ^+ -impurity interaction is unnecessary, provided that the interaction has reasonably short range.³ In this paper, we consider further the nature of this interaction.

In previous reports,¹⁻⁴ we described the temperature dependence of Λ for several samples, primarily in low transverse magnetic fields (80 Oe). Here, we report on measurements of the magnetic field dependence of Λ , in the range 0-5 kOe, for AgGd (340 ppm), AgEr (300 ppm), and AuGd (350 ppm). A description of the experimental apparatus and the details of sample preparation are given in ref. 3. For each sample, the temperature chosen corresponds to the peak in Λ vs T . Transverse-field ($H_{\perp}$) data were taken for all three samples and longitudinal-field ($H_{\parallel}$) data for AuGd (350 ppm) only. The results are shown in Fig. 1, where Λ is normalized to its zero-field value; the curves are model² fits as discussed below.

In addition to the two diffusion parameters mentioned above, two other free parameters enter the model: the strength of the nearest-neighbor contact interaction given by $A = \gamma_{\mu} H_X/S$ and the impurity spin-lattice relaxation rate, given by the Korringa form $\tau_s^{-1} = b_s \gamma_s T$. Here, S is the impurity spin, and b_s and H_X are free parameters. In all of the model fits, the diffusion parameters were held fixed at the values determined previously.^{3,4} In Fig. 1, the dashed curves result from using the values of b_s and H_X obtained previously from fits to the Λ vs T data. The solid curves result from attempting to fit the field-dependent data with new values of b_s and H_X . These new values yield poor fits to the Λ vs T data. In Table I, we compare these parameters.

Obviously our model, which is based on conventional relaxation theory,⁵ does not contain the correct field dependence. The field-dependent part of Λ is given by $\Lambda = \tau_c [1 + (\gamma_s H \tau_c)^2]^{-1}$, where the effective correlation time τ_c is related to τ_s and the hopping time τ_h by $\tau_c^{-1} = \tau_s^{-1} + \tau_h^{-1}$.² At the temperatures of interest here, τ_s and τ_h are of comparable magnitude. Without modifying the conventional theory, τ_s would have to be field-dependent in order to agree with the data; however, it is not obvious what mechanism of impurity-spin relaxation would have this behavior.

Missing from our Hamiltonian is any effect the muon has on the magnetic impurity itself. The electric field gradient V induced by the muon at the impurity site leads to an axial crystal-field term $\mathcal{H}_0 = DS_z^2$. For a non-S-state ion (Er^{3+}), the relation between D and V is⁶ $D = 0.75 e \langle J || \alpha || J \rangle V \langle r^2 \rangle$, where $\langle r^2 \rangle$ is the mean square f-electron radius and $\langle J || \alpha || J \rangle$ is a numerical constant.⁶ Using V as measured in Cu⁷ (which should be approximately correct for Ag and Au) and $\langle r^2 \rangle$ as given in ref. 8, we obtain $D = 50$ kOe (in field units). For an S-state ion (Gd^{3+}), a recent calculation⁹ yields $D = 0.75 e K_2 \gamma_2 V \langle r^2 \rangle$, where K_2 and γ_2 are given in ref. 9 for Gd^{3+} . We obtain $D = 10$ kOe. Clearly, $\mathcal{H}_0$ is the dominant term in the Hamiltonian and must be included in deriving the muon depolarization expressions.

We have estimated Λ in the high-field limit ($D \gg \gamma_s H \gg \tau_c^{-1}$) and have found these asymptotic values to be significantly greater than those obtained from conventional theory (dashed lines in Fig. 1). The full calculation, keeping all of the significant field-dependent terms, is somewhat tedious and is currently in progress. When this calculation is

finished, the correct relaxation expressions will then be incorporated into our hopping model to obtain $\Lambda(H)$.

REFERENCES

- [1] R.H. Heffner, *Hyp. Int.* 9 (1981) 655.
- [2] M.E. Schillaci, R.L. Hutson, R.H. Heffner, M. Leon, S.A. Dodds, and T.L. Estle, *Hyp. Int.* 8 (1981) 663.
- [3] J.A. Brown, R.H. Heffner, R.L. Hutson, S. Kohn, M. Leon, C.E. Olsen, M.E. Schillaci, S.A. Dodds, T.L. Estle, D.A. Vanderwater, P.M. Richards, and O.D. McMasters, *Phys. Rev. Lett.* 47 (1981) 261.
- [4] M.E. Schillaci, C. Boekema, R.H. Heffner, R.L. Hutson, M. Leon, C.E. Olsen, S.A. Dodds, D.E. MacLaughlin, and P.M. Richards, "Muon Diffusion in Noble Metals," *Proc. Int. Symp. on the Electronic Structure and Properties of Hydrogen in Metals* (Plenum, New York) to be published.
- [5] A. Abragam, The Principles of Nuclear Magnetism (Oxford, London, 1961).
- [6] A. Abragam and B. Bleaney, Electron Paramagnetic Resonance of Transition Ions (Oxford, London, 1970) Sec. 5.3 and table 20.
- [7] A. Schenck, *Helv. Phys. Acta* 54 (1981) 471.
- [8] A.J. Freeman and R.E. Watson, *Phys. Rev.* 127 (1962) 2058.
- [9] N.R. Lewis and S.K. Misra, *Phys. Rev.* B25 (1982) 5421.

Table I. Fitted Values of Model Parameters b_s and H_x .

		<u>AuGd</u>	<u>AgGd</u>	<u>AgEr</u>
[Λ vs T]	b_s (Oe/K)	4.3	0.77	1.9
	H_x (kOe)	20.0	16.0	0
[Λ vs H]	b_s (Oe/K)	30.0	6.4	12.0
	H_x (kOe)	54.0	50.0	30.0

FIGURE CAPTION

Fig. 1. Magnetic field dependence of muon depolarization rate for (a) AgGd, (b) AgEr, (c) AuGd in transverse field ($H_{\perp}$) and for (d) AuGd in longitudinal field ($H_{\parallel}$). The curves are model fits as described in the text.