NUCLEAR RELAXATION OF Ag109m IN IRON DETECTED BY NUCLEAR ORIENTATION

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Résumé. — L'étude de l'orientation nucléaire de Ag^{109m} dans Fe à $T \sim 0{,}015$ °K a conduit à une dépendance anormale du champ hyperfin apparent en fonction de la température. Cet effet est interprété par un réalignement partiel des noyaux pendant le temps de vie de 40 secondes de l'état intermédiaire. Puisque dans les conditions de l'expérience $h\nu_n \geqslant kT$, les théories de la relaxation nucléaire d'impuretés dissoutes dans les métaux ont été étendues à la région où l'approximation des hautes températures n'est pas valable. A l'aide des résultats on a pu obtenir les valeurs du champ hyperfin réel et de T_1 T pour Ag dans Fe.

Abstract. — A nuclear orientation study of Ag^{109m} in Fe at $T \sim 0.015$ °K has led to an unusual temperature dependence of the apparent hyperfine field. This effect has been interpreted as a partial realignment of the nucleus during the lifetime of the 40 second intermediate nuclear state. Since in the conditions of the experiment $h\nu_n \geqslant kT$, theories for the nuclear relaxation of dilute impurities in metals have been extended to the region where the high temperature approximation is not valid. The experimental results have been analysed to give values of T_1T and the real hiperfine field for Ag in Fe.

There has been recent interest in nuclear spinlattice relaxation in ferromagnetic metals at very low temperatures (0.01 °K). Two methods of experimentally investigating this phenomenon have been suggested and applied to several cases (1) (2). However both these methods suffer from the disadvantage that the initial state of the system before relaxation is unknown, so that a further parameter is introduced into any theoretical fit to the results.

A system in which this disadvantage is absent occurs for the metastable 88 keV (7/2 +) state of $^{109}Ag^m$ which is populated by electronic capture from ^{109}Cd (5/2 +). Knowledge of the hiperfine splitting for ^{109}Cd in Fe, together with the lattice temperature, enables the nuclear level populations of ^{109} Cd to be calculated and hence also the initial populations in the 40s lifetime 88 keV state of ^{109}Ag.

The hyperfine interaction in ^{109}Ag differs in sign from that of ^{109}Cd, so that these initial populations happen to be very far from thermal equilibrium. Since the lifetime of the 88 keV state is comparable to typical nuclear relaxation times at the temperatures of interest, the partial relaxation of the populations in the intermediate state will thus severely affect the measured anisotropy. Neglecting it would lead to a temperature depend hyperfine field.

In order to take this kind of relaxation effect into account, previous studies has used a spin temperature model, [4] but this model is unlikely to be valid in the case reported here, because of the very high dilution of the $^{109}Ag^m$ nuclei*. We shall therefore use the theory of ref. [3] which assumes independent relaxations of the different nuclei through their interaction with the conduction electrons

$$\mathcal{H} = \Gamma \mathbf{I}.\mathbf{S}.\delta(\mathbf{R} - \mathbf{r}) \qquad (1)$$

(1) The most effective interaction for establishing a spin temperature at low concentrations would be the Suhl-Nakamura interaction, but its effect are certainly negligible below 1 ppm while the concentration of Ag^{109m} nuclei is $\sim 10^{-10}$.

In these conditions one can show that the evolution of the populations of the intermediate nuclear state is given by

$$\frac{dp_m}{dt} = -(W_{m,m-1} + W_{m,m+1})\, p_m + W_{m+1,m}\, p_{m+1} + W_{m-1,m}\, p_{m-1} \cdot \qquad (2)$$

$$W_{m,m+1} = \frac{1}{T_1'}\left| < m+1 \left| \frac{I^+}{\sqrt{2}} \right| m > \right|^2 ; \qquad W_{m,m-1} = \frac{1}{T_1''}\left| < m-1 \left| \frac{I^-}{\sqrt{2}} \right| m > \right|^2 . \qquad (3)$$

$$\frac{T_1''}{T_1'} = \exp\left(-\frac{\hbar\omega_n}{k_B T}\right) ; \quad \left(\frac{1}{T_1'}\right) + \left(\frac{1}{T_1''}\right) = \frac{2}{T_1} \qquad (4)$$

$$\frac{1}{T_1} = C \coth\left(\frac{\hbar\omega_n}{2 k_B T}\right) \sum_{qq'} \mathrm{Im}\, \chi(q, q', \omega_n) \qquad (5)$$

in which $\sum_{qq'} \mathrm{Im}\chi(q, q', \omega_n)$ is the imaginary part $(\alpha\omega_n)$ of the transverse electronic susceptibilityat the impurity site. This susceptibility being practically temperature independent, $1/T_1$ has the form

$$\frac{1}{T_1} = \frac{\hbar\omega_n}{2 A k_B} \coth \frac{\hbar\omega_n}{2 k_B T} \qquad (6)$$

which, at high temperatures, reduces to the Korringa law : $T_1\ T$ = cte.

Having solved the equations of evolution of the populations one gets the ray anisotropy :

$$W(\theta) \to \frac{1}{\tau}\int_0^\infty dt\, e^{-t/\tau} \sum_{k\ \mathrm{even}} B_k(t)\, F_k\, P_k(\cos\theta) \qquad (7)$$

in which the B_k's are related to the populations in the conventional way :

$$B_k = \sqrt{2I+1} \sum_m p_m < m \mid T_k^0 \mid m > \qquad (8)$$

and τ is the lifetime of the intermediate state.

In order to interpret the experimental data, the equations of evolution of the populations (2) have been solved numerically using a computer. A first two parameters fit for $1/T_1$ (A and ω_n in Eq. (6)) had yielded $A \sim 0.5$ and H_n

$$\text{(hyperfine field)} = 440 \pm 40 \text{ kOe.}$$

Since then, resonant destruction of nuclear orientation of $^{110}Ag^m$ in the same matrix has been observed ;

$$H_n = 441 \pm 5 \text{ kOe}$$

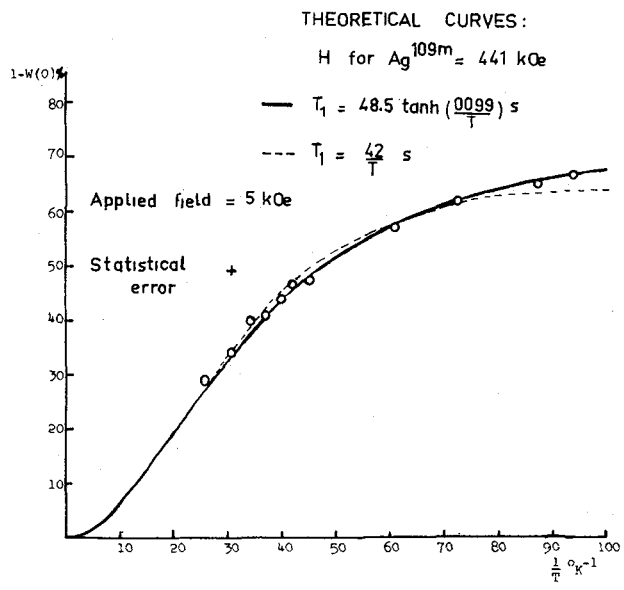

FIG. 1.

and, after correcting for the hyperfine anomaly, the results of this experiment would lead to

$$H_n = 441 \pm 5 \text{ kOe}$$

for $^{109}Ag^m$, in very good agreement with the first determination.

Using this last value of H_n, a one parameter fit has been done (Fig. 1) leading to an excellent agreement with experimental data taking $A = 0.48 \pm 0.03$ sec. K in eq. (6). Figure 2 exhibits the values of T_1 resulting

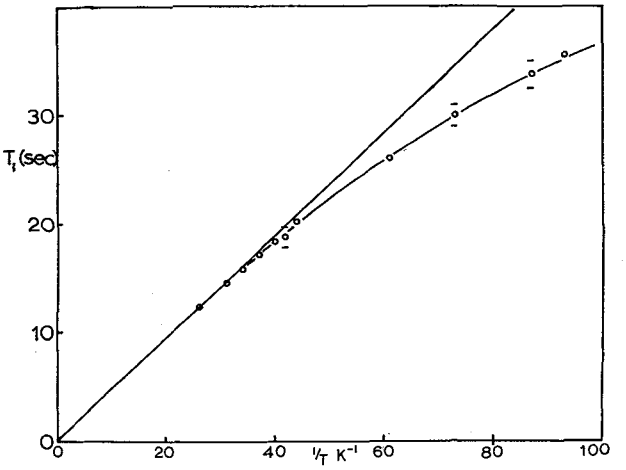

FIG. 2.

from fitting the data at each lattice temperature, plotted against the lattice temperature. The data show good agreement with the theoretical tanh ($\hbar\omega_n/2\ k_B\ T$) temperature dependence. The deviation from the linear Korringa law is appreciable.

References

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