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NUCLEAR ORIENTATION-MAGNETIC RESONANCE OF $^{48}$V NUCLEI IN IRON

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Abstract.- Observations via $\gamma$-radiation anisotropy measurements of the nmr of $^{48}$V nuclei in iron are reported and lead to a value of $2.01 \pm 0.01$ nm for the nuclear magnetic moment. The application of pulsed rf fields for systems with long ($\gtrsim$h) spin-lattice relaxation times is discussed.

The first reported attempt to study nuclear orientation of $^{48}$V in iron was that of Kogan et al /I/ who did not detect any anisotropy in the 0.99 and 1.31 MeV $\gamma$-radiations at a temperature of 0.03 K. Later Cameron et al. /2/, using temperatures $\gtrsim 14$ mK, observed anisotropies $\sim 1\%$ and deduced a value $|\mu(48V)| = 1.63 \pm 0.1$ nm. We have been measuring the radioactivity in the temperature range 3.5-7 nm and have observed anisotropies $\sim 50\%$ higher than those expected from the results of Cameron et al. This difference may be partly due to the better accuracy obtainable with the lower temperatures and the Ge(Li) detectors used here; however the main reason is probably associated with the very long ($\gtrsim$ several hours) values of the nuclear spin-lattice relaxation time T1, which we have observed and the consequent need to wait until the nuclei reach spin equilibrium before making anisotropy measurements. Details of the anisotropy and relaxation measurements will be published elsewhere; we report here on observations via radiative detection of the nmr.

The sample was prepared by evaporating a few $\mu$Ci of $^{48}$V activity from methanolic solution onto Fe foil, diffusing 4 days in $H_2$ at 1200 C and then cold rolling to a thickness of 12 $\mu$. It was cooled to $\approx 3.5$ mK in a standard CNM demagnetization cryostat which included an rf coil for producing the rf fields. A weak ($\sim 0.1\mu$Ci) $^{54}$Mn in Ni sample was used for thermometry. The $^{48}$V $\gamma$-radiations emitted along the orientation axis were monitored with an Na(I) scintillation detector. For the thermometry the $^{54}$Mn $\gamma$-radiation emitted at right angles to this axis was monitored with a Ge(Li) detector. The choice of the relative sample activities and the detection system was to optimize our sensitivity to changes in the $^{48}$V orientation during the resonance experiments; for the more accurate anisotropy measurements to be published separately two Ge(Li) detectors and $^{60}$Co in Fe thermometer were used.

In the CW experiments a frequency modulated rf field was used and the centre frequency slowly swept through the region of interest. After each demagnetization we waited several hours to allow the $^{48}$V nuclei to come to approximate thermal equilibrium with the host lattice; this was facilitated by the use of zero applied field during this period, thus using the faster spin-lattice relaxation at low fields. When the applied field was swept up, appreciable heating of the $^{48}$V did not occur, indicating the adiabatic establishment of the nuclear magnetization /3/. In figure 1 the dependence of W(0), the normalized $\gamma$-emission intensity, upon the rf centre frequency is shown for an applied field $H_0 = 0.42$ T and for both sweep directions. The asymmetric resonance shapes are caused by the relatively fast resonant disorientation as the rf moves through the resonance, followed by the slow spin-lattice relaxation. Because of this the resonant frequencies $f_0$ should correspond to the centres of the disorientation regions rather than to the peaks of the observed line shapes; from the CW experiments we obtain $f_0 = 32.95 \pm 0.1$ and $31.8 \pm 0.1$ MHz for $H_0 = 0.12$ and 0.42 T respectively.

The results in figure 1 indicate the diffi-
culties in obtaining true resonance lineshapes with long $T_1$ values; a very approximately integral line is observed in the disorientation region and also extremely good temperature stability is required for long periods to reduce baseline effects.

![Fig. 1](image1)

**Fig. 1**: Frequency (and hence also time)-dependence of the axial radiation anisotropy $W(0)$ with $T = 6 \, mK$, $H_0 = 0.42 \, T$, modulation amplitude 100 kHz modulation frequency 10 Hz and sweep times of 2 and 3 h for sweep up and down respectively.

We have found that under these conditions the pulsed FM technique, as previously used by the Dunstroon /4/ group to study resonance in high applied fields, leads to an easier and more definite determination of the resonance; a more intense rf field than could be used in the CW experiments is frequency modulated and pulsed on for a time $\ll T_1$ and the subsequent time dependence of the radiation anisotropy is observed. This is illustrated in figure 2a where the effects of 2 sec. pulses on $W(0)$ is shown. The genuine nature of the signal is indicated by the absence of a signal from the pulse without FM, an essential property of such experiments on ferromagnets with an rf field $H$, such that $\gamma H < \Delta$, the inhomogeneous line width /5/. Because the FM pulse produces such an abrupt change in $W(0)$ this change may be accurately determined regardless of the value of $T_1$, or of any variations in the baseline. Such pulses were applied for a variety of centre frequencies and figure 2b shows the fractional change in radiation anisotropy as a function of the centre frequency thus leading directly to the resonance lineshapes. From these we obtain $f_0 = 32.85 \pm 0.1$ and $31.75 \pm 0.1$ MHz for $H_0 = 0.12$ and $0.42 \, T$ respectively. The deduced inhomogeneous linewidth (FWHM) is 280 kHz. The results verify that the hyperfine field is negative and, from the known /6,7/ value of $-8.71 \, T$ for the hyperfine field we obtain a value $|\mu^{(HF)}| = 2.01 \pm 0.01 \, nm$.

![Fig. 2a](image2)

**Fig. 2a**: Time dependence of $W(0)$ during which two 2 s rf pulses (with and without FM as marked) were applied.

![Fig. 2b](image3)

**Fig. 2b**: Dependence of pulsed FM signal, fractional change in $[1 - W(0)]$, upon centre frequency with a modulation amplitude of 75 kHz.

**References**


/4/ Foster, H.R., Chaplin, D.H. and Wilson, G.V.H., to be published

