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NEW APPLICATIONS OF NUCLEAR COOLING IN NUCLEAR ORIENTATION STUDIES

G.V.H. Wilson, K. Bures, W. Brewer, J. Boysen,
Fachbereich Physik der Freien Universität Berlin, 1 Berlin 33, W. Germany.

Abstract.—The application of adiabatic "cooling" and "warming" of the radioactive oriented probe nuclei to relaxation measurements is demonstrated. Also it is shown how the conventional CMN demagnetization cryostats used in such studies may be extended to the 1-2 mK region by nuclear cooling of the copper heat link.

We have recently carried out nuclear orientation studies of the hyperfine interactions and spin-lattice relaxation of $^{88}$V nuclei in iron and cobalt hosts. A full account of these measurements will be published elsewhere; we report here on some novel applications of nuclear cooling developed during these experiments. A description of some nuclear orientation-magnetic resonance results is given in an accompanying paper /1/.

A standard CMN demagnetization cryostat was used, having a main salt pill with about 300 g. of CMN powder in glycerin slurry. Contact to the sample was made through the 3000 cm$^2$ area of silver foils which were attached by a screw joint to a heat link of 0.3 mm dia. Cu wires with cross sectional area of 0.3 cm$^2$ and 15 cm length. A 4 T compensated superconducting solenoid was used to polarize the sample; with the maximum polarizing field, about the lower 10 cm of the heat link was subjected to a field of at least 2 T.

The $^{4}$VFe sample used was as in /1/ and was mounted with a $^{60}$CoFe thermometer. The $^{88}$VCo sample was prepared in a similar manner using 4N Co foil of 25 μm thickness; it was mounted with a $^{4}$CoNi thermometer which permitted greater accuracy in the lower temperature (T<3 mK) experiments. Two Ge(Li) gamma detectors were used together with an on-line computer for the data collection.

The nuclear orientation at thermal equilibrium is a function of nuclear parameters, which are all known for $^{88}$V, and of the hyperfine splitting which was determined in the resonance studies /1/. Thus, measurements of the gamma-ray anisotropy as a function of time after or during temperature changes may be used to study the spin-lattice relaxation of the $^{88}$V nuclei. For V in cobalt the magnetic hyperfine field is known to be ± 4.9 T /2/; our results show that the negative sign is correct.

In the temperature range used, the spin-lattice relaxation times for $^{88}$V in Fe and Co are 2-20 h., and because of the relatively fast cooling of the sample after a demagnetization, it is possible simply to monitor the gamma anisotropy as a function of time after cooling. Analysis using the usual angular distribution function then yields the $^{88}$V nuclear orientation. Such "fast" cooling experiments have previously been carried out on $^{62}$ZnFe with $T_{1\text{f}} = 14.7±2.5$ sK /3/ and on $^{62}$CoFe with $T_{1\text{f}} = 2$ sK /4,5/. These experiments, together with those employing pulsed heating, have considerable advantage over resonant methods because of the more accurately known initial conditions for the relaxation /6/.

In the present experiments, because of the long relaxation times at millikelvin temperatures, and because the hyperfine fields are comparable with available applied fields, it is also possible to control the V nuclear spin temperature in a known way, after thermal equilibrium with the lattice is attained, by varying the applied field. This has two advantages: it enables relaxation data to be obtained for both polarities of the initial temperature difference between the nuclei and the lattice and it permits relaxation measurements in high applied fields, where, because of the negative hyperfine fields, the equilibrium gamma anisotropies would be small. This is illustrated in figure 1; at t=0 the demagnetization of the CMN was completed thereafter the spin temperature of the $^{88}$V nuclei
relaxes slowly towards $T_L$.

At $t = 5.7$ h, after the nuclei are in equilibrium with the lattice, the polarizing field on the sample is swept from 0.18 T to 2.54 T during 20 min. During this time the $^{56}$Fe nuclei may be assumed to remain thermally isolated because of the long $T_1$; as their resultant field is lowered from 8.53 to 6.17 T they will cool from 4.3 mK to 3.1 mK. They then relax towards the lower orientation expected in the 2.54 T polarizing field. At $t = 8.7$ h the field was swept back to 0.18 T to produce warming of the $^{48}$As nuclei. Preliminary values of the Korrings constants for Fe and Co hosts, respectively, are $45 \pm 5$ sK and $80 \pm 10$ sK.

The time variation of the lattice temperature as in figure 1 indicated some unexpectedly large effects of the fringing field from the polarizing coil on the nuclei of the copper heat link. Later experiments confirmed that neither the stray field of the CMN nor eddy currents during field sweeps produced significant heating; the dominant effects come from nuclear adiabatic magnetization and demagnetization of the copper. At low temperatures, the thermal contact between the CMN slurry and the copper is sufficiently poor that very long time constants are observed for thermal relaxation after changing the polarizing field. We have therefore investigated the possibility of enhancing the performance of the (unmodified) cryostat by utilizing the nuclear cooling of the copper heat link.

In these experiments the CMN was demagnetized in the usual manner but with a 4 T polarizing field on the sample from the start. The time dependence for the temperature of the $^{60}$CoN thermometer for two different experiments are shown in figure 2.

References

1/ Bures, K., Brewer, W., Wilson, G.V.H., this conference.