

PULSED NMR EXPERIMENTS ON AuIn₂ WITH RESPECT TO ITS PERFORMANCE AS A NUCLEAR REFRIGERANTK. Andres and B. Millimill[†] **Bell Laboratories, Murray Hill, N.J. USA*[†]*Zentralinstitut für Tieftemperaturforschung, 8046 Garching, Germany*

Résumé.- Les propriétés dynamiques des spins ¹¹⁵In dans AuIn₂ ont été étudiées par la RMN à impulsions dans des champs magnétiques de 74,3 mT et de 38,5 mT à des températures jusqu'à 25 mK. Du temps de corrélation spin-spin mesuré, on a déduit une température d'ordre nucléaire de 1,1 μK. On a trouvé un temps de relaxation spin-réseau dépendant du champ magnétique mais toujours un ordre de grandeur plus court que celui de Cu. Les avantages de AuIn₂ en tant que réfrigérant nucléaire sont discutés.

Abstract.- The dynamic properties of ¹¹⁵In spins in AuIn₂ were studied with pulsed NMR in fields of 74.3 mT and 38.5 mT down to 25 mK. From the measured spin-spin correlation time a nuclear ordering temperature of 1.1 μK is deduced. The spin-lattice relaxation time is found to be field dependent but still an order of magnitude shorter than that of Cu. The advantages of AuIn₂ as a nuclear refrigerant are discussed.

With In as nuclear refrigerant a higher cooling power and a shorter thermal response time should be possible than with Cu which is normally used. However, the quadruple interaction as well as the high critical field H_{CO} limits the application of In at temperatures $T > 0.1$ mK. Lower T , though, should be obtainable in the alloy AuIn₂ where the In atoms are located in cubic symmetry and which has a H_{CO} as low as 1.66 mT /1/.

In view of this aspect we have performed pulsed NMR experiments on ¹¹⁵In in AuIn₂ at two magnetic fields H_0 or 74.3 mT and 38.5 mT and in a temperature range from 25 mK to 100 mK. From the free induction decay (FIS) the spin-spin correlation time T_2 is determined which is inversely proportional to the spontaneous ordering temperature of the system. Also the spin-lattice relaxation time T_1 was measured in order to verify the small Korringa constant $\kappa = T \cdot T_1 = 91(4)$ mK's obtained earlier at high T in high H_0 /2/.

Our AuIn₂ samples was made from the same bulk material as used by Andres and Wernick /1/ and ground to a particle size of ~ 20 μm. The powder was not annealed. The field homogeneity over the sample volume was $\sim 5 \times 10^{-6}$. The measurements were done in the mixing chamber of a dilution cryostat.

* "Bavarian Millimill" is a joint project of G. Eska, N. Kartascheff, J. Kraus, K. Neumaier, K. Uhlig, W. Wiedemann (ZTF), W. Schoepe (Universität Regensburg) and P. Wölfle (Technische Universität München) It is supported by the Deutsche Forschungsgemeinschaft.

A typical result for the amplitude of the FIS is shown in figure 1. It is obvious that the decay is not a simple exponential. The extreme

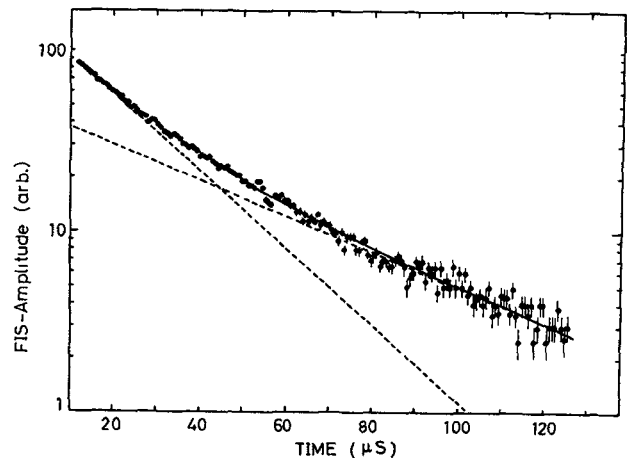


Fig. 1 : Free Induction Signal of ¹¹⁵In in AuIn₂ at $H_0 = 74.3$ mT and $T = 25$ mK : tipping angle is 64° corresponding to maximum transverse magnetization. The data can be fitted by two time constants (dashed lines).

values of T_2 are 15 (1) μs and 44(3) μs (dashed lines). This behaviour is found to be independent of T and H_0 and can neither be attributed to inhomogeneities of H_0 nor to transients of the coil system itself. We observed, however, that the contribution of the faster decay to the signal decreased rapidly with increasing pulse length, i.e. narrower bandwidth around the Larmor frequency. Therefore,

we attribute the longer T_2 to the Zeeman splitting and the shorter one mostly to strong quadrupole interaction caused by strains and imperfections in the sample. From ref. /1/ it is known that in bulk material quadrupole effects are negligible. Taking $T_2 = 44 \mu\text{s}$ we deduce a nuclear ordering temperature of $1.1 \mu\text{K}$ for bulk AuIn_2 .

Figure 2 shows some results of the T_1 measurements taken in a time interval $200 \mu\text{s} \leq t \leq 10 \text{ s}$.

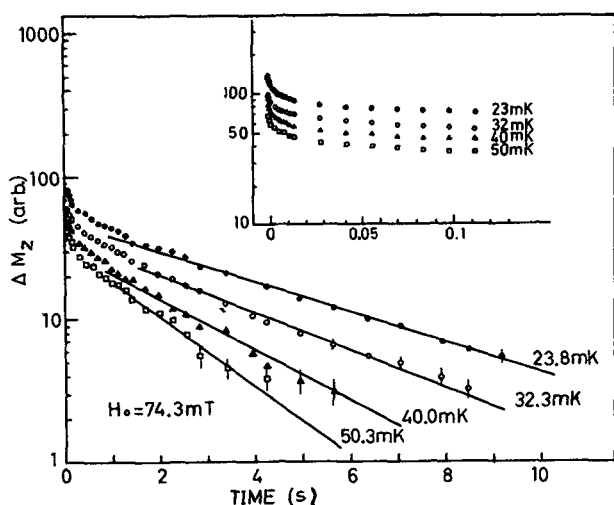


Fig. 2 : Relaxation of the longitudinal magnetization to equilibrium after a π pulse. Straight lines correspond to the Korringa constant of ref. /2/. The insert shows the early time behaviour in an expanded time scale.

Similar results were found for $H_0 = 38.5 \text{ mT}$. The relaxation for short times after a π tipping pulse is far off from the Korringa behaviour indicated by the straight lines corresponding to $\kappa = 91 \text{ mK}^2/\text{s}$. The short-time relaxation rate is compiled in figure 3 for different H_0 , tipping angles and bath temperatures. A striking feature of all these data is a universal power-law time dependence up to 0.5 s , although the temperatures of the conduction electrons are quite different due to different eddy current heating. The non-exponential relaxation is presumably caused by strain-induced quadrupole interaction which in addition leads to a wide distribution of energy levels and hence to an incomplete saturation of the spin system by the π pulse. Since it is unknown how much all possible relaxation channels are contributing to the decay we consider the total rate as the sum of a time dependent part and the Korringa part in order to fit the data. The Korringa constant κ was found to be

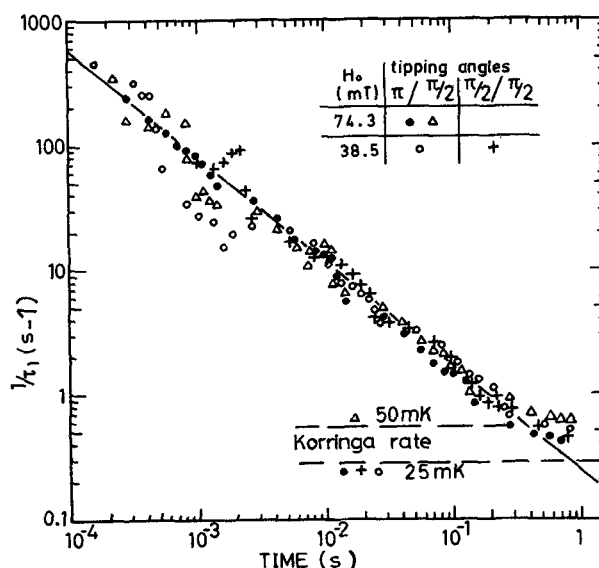


Fig. 3 : Spin-Lattice relaxation rate vs. time for different experimental conditions. Dashed lines indicate the Korringa rate.

field dependent and we obtain $112(2) \text{ mK}^2/\text{s}$ at 74.3 mT and $82(5) \text{ mK}^2/\text{s}$ at 38.5 mT .

Comparing AuIn_2 with Cu as nuclear refrigerant (assuming the same volume, heat leak and initial conditions H_1/T_1) we calculate the lowest possible electronic temperature T_{min}^e (AuIn_2) to be a factor of 4 less than T_{min}^e (Cu). With a heat leak of 30 pW/cm^3 the warm up time to T_{min}^e (Cu) is $37.H_1/T_1$ seconds, i.e. in general some hours. Alternatively, stopping demagnetization at T_{min}^e (Cu) the cooling power of AuIn_2 is larger by a factor of 5.8. This in conjunction with the 10 times shorter T_1 than that of Cu makes AuIn_2 a promising candidate for nuclear refrigeration.

References

- /1/ Andres, K. and Wernick, J.H., Rev.Sci.Instrum. 44 (1973) 1186
- /2/ Warren, W.W., Shaw, R.W., Menth, A., DiSalvo, F.J., Storm, A.R. and Wernick, J.H., Phys.Rev. B 7 (1973) 1247.