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STUDY OF SPIN DYNAMICS IN NdRh_2Si_2 CRYSTALS BY μSR RELAXATION MEASUREMENTS

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We have studied by zero-field and longitudinal field μSR measurements the uniaxial antiferromagnetic intermetallics NdRh_2Si_2 . The measurements have been performed on single crystals. Our data show that the magnetic field at the muon site is parallel to the c axis. Below the Néel temperature T_N the spin-lattice relaxation is driven by a two magnon process. In the paramagnetic region near T_N we observe, a critical divergence of the damping rate.

Recently it has been shown that the critical magnetic properties of metallic thulium and erbium are still not understood [1]. These metals order at relatively high remperature ($\sim 58\text{ K}$ and $\sim 86\text{ K}$ respectively) in a longitudinally modulated antiferromagnetic structure. Therefore the critical dynamics of magnets is still a subject of current interest. Almost ten years ago it was first shown that μSR spectroscopy was able to give useful information on the critical dynamics of insulating antiferromagnets [2]. Recently a μSR experimental study of erbium has been presented [3]. In this paper we report preliminary μSR results obtained on the simple metallic antiferromagnet NdRh_2Si_2 . Because this compound has a simpler magnetic structure than the elemental rare-earth metals, one may hope that the data

will be easily amenable to a theoretical understanding. The dynamical properties of magnets in their ordered state are an interesting subject by their own. In this paper we show that μ SR relaxation measurements are able to give information on the spin dynamics of antiferromagnets for $T < T_N$. The nice advantage of μ SR is that the measurements can easily be made in any magnet. If the muon localisation site can be determined, one may hope to get essential information as shown recently for ferromagnets [4].

The ternary intermetallic compound $NdRh_2Si_2$ crystallizes in the tetragonal $ThCr_2Si_2$ -type structure. It has only one magnetic phase transition which occurs at $T_N \simeq 57$ K. At low temperature the Nd^{3+} magnetic moments form a collinear antiferromagnetic structure which is described as a sequence of ferromagnetic (001) planes stacked in the direction of the c axis with the sequence $+-+-$. The magnetic moments point along the c axis [5]. Results obtained for a polycrystalline sample have already been presented [6]. In this paper we report preliminary data taken on single crystals.

The measurements have been performed at the μ SR spectrometer of the ISIS facility located at the Rutherford Appleton Laboratory (UK). The data have been recorded from 335 K to 12.5 K with the longitudinal experimental set-up. They have been analysed following a well established method [7]. Basically the positrons are recorded in two detector arrays which are positionned along the muon beam direction. The eight spectra from the forward array are added together to give a single spectrum $M_+(t)$ and the eight spectra from the backward array are likewise combined to give a single spectrum $M_-(t)$. Then the following ratio is formed:

$$R_{exp}(t) = \frac{M_+(t) - \alpha M_-(t)}{M_+(t) + \alpha M_-(t)}, \quad (1)$$

where α is the instrument forward/backward counting rate ratio. $R_{exp}(t)$ is directly fitted to the model depolarisation function. The coefficient α is determined by recording a spectrum taken with an applied magnetic field of 20 Oe without changing the geometry around the sample. The α value is adjusted to get the wiggles of $R_{exp}(t)$ oscillating around zero. Notice that the determination of α has to be performed in the paramagnetic state. This method of analysis works quite well at ISIS because for a pulsed muon beam there is no electronic background. Routinely we fully describe the two pulse structure of the beam by a convolution technique [7]. With this method the initial asymmetry is properly determined even if the damping rate is large. It turns out that, for the present work, this is essential only for two data points (see Fig. 2). We have used two samples: the c axis is either parallel

Fig. 1. Temperature dependence of the damping rate measured on a single crystal of NdRh_2Si_2 . The initial muon beam polarisation is parallel to the c axis. The dashed line gives the prediction for a quadratic temperature dependence of the damping rate in the ordered state.

or perpendicular to the sample plane. Each sample is a mosaic of single crystals as shown in Ref. [8]. The samples have been respectively grown and cut at the universities of Amsterdam and Leiden. In the figures of this paper the direction of the initial muon beam polarisation relative to the c axis is indicated by a pictogram.

When the initial beam polarisation is parallel to the c axis the initial asymmetry keeps a constant value (~ 0.17) all the way down to 12.5 K. In contrast, when the polarisation is perpendicular to that axis the μSR signal disappears suddenly at ~ 56.9 K. At low temperature, below $T_N \sim 56.9$ K, we do not see the μSR signal in this latter compound probably because the precession frequency of the muon spin is too high to be detected with the ISIS spectrometer [9]. The results we have just described demonstrate that the magnetic field at the muon site is parallel to the c axis. This is consistent with results obtained on other compounds of the same family [9]. The precision in our determination of the value of T_N (~ 0.1 K) is limited by the temperature stability of the cryostat.

The spectra recorded for the two samples can be described by exponential depolarisation functions. In Fig. 1 and Fig. 2 we present the temperature dependence of the depolarisation rates. Some of the spectra have been

Fig. 2. Temperature dependence of the damping rate measured on a single crystal of NdRh_2Si_2 . The initial muon beam polarisation is perpendicular to the c axis.

recorded with a longitudinally applied magnetic field.

First we discuss the data of Fig. 1. We notice that while there is a weak field dependence of the damping rate λ_Z (the zero-field damping rate are larger than the rate extracted from the spectra recorded with an applied magnetic field), it seems that the data recorded at 5 mT and 200 mT give the same value. This is easily understandable if we attribute this weak field dependence to the nuclear magnetic moments of the compounds. Therefore λ_Z recorded at 5 mT and 200 mT are only influenced by the electronic magnetic moments. λ_Z is, below T_N , a measure of the spin-lattice relaxation rate. This rate decreases slowly with the temperature as expected if the muon spin depolarisation is due to a two magnon (Raman) process. This process has already been identified in a weakly anisotropic ferromagnet [8]. In this case λ_Z is proportionnal to $T^2 \ln(T)$ [4]. Although such a type of dependence is expected for an antiferromagnet [11] (roughly speaking, at the temperatures where the measurements are made, each magnon gives a linear temperature dependence to the damping; because the depolarisation process involves two magnons, the damping has a quadratic thermal dependence), the theoretical study of λ_Z for such a magnet has not been performed up to now. As a guide in Fig. 1 we have drawn a dashed line which gives the prediction for a quadratic dependence. Although this does not describe the data perfectly well, it is quite reasonable. In the param-

agnetic region λ_Z is practically temperature independent. The very weak increase of λ_Z near T_N may be attributed to a slight misalignment of the muon beam polarisation relative to the c axis. If we suppose that the fluctuations of the magnetic field at the muon site follow in an isotropic way the fluctuations of the Nd^{3+} magnetic moments (i.e. the coupling between the muon spin and the moments is effectively isotropic), this λ_Z behaviour is expected because $NdRh_2Si_2$ is an uniaxial magnet. We note that the validity of this hypothesis is not obvious. The relation between the field at the muon and the moments has to be studied in details as it has been done recently for some ferromagnets [4].

We now discuss the temperature behaviour of λ_Z when the initial muon beam polarisation is perpendicular to the c axis. We first note that if the hypothesis we have mentioned at the end of the previous paragraph is valid, $\lambda_Z(T)$ presented at Fig. 2 reflects directly the spin dynamics along the c axis. We clearly see the slowing down of this dynamics as T_N is approached from above: λ_Z is multiplied by a factor of ~ 200 near T_N compared to its value at high temperature. (Notice that the vertical scale of Fig. 2 is logarithmic whereas the one of Fig. 1 is linear.) Because during the measurements we did not have the required temperature stability to really study the critical dynamics we will not give a detailed analysis of our data. We only note that if we take $T_N = 56.9$ K and plot λ_Z in a logarithmic plot, we find that $\lambda_Z(T)$ follows a power law behaviour with a critical exponent of $w \sim 0.9$. We hope in the near future to be able to measure $\lambda_Z(T)$ near T_N with the required precision to extract quantitative information on the spin dynamics of an axial antiferromagnet.

It is tempting to compare the present damping rate results with the erbium results recently published [3]. Because for erbium below T_N there are many magnetic phase transitions (see Ref. [3] for references) it has not been possible (at least up to now) to identify the relaxation process as we have just done for $NdRh_2Si_2$. In the paramagnetic region, qualitatively the rates have the same temperature behaviour. But quantitatively there is a big difference: whereas, for $NdRh_2Si_2$ the damping rate is about 200 times larger near T_N relative to its high temperature value, there is only a factor of about 2.7 for erbium (see Fig. 2 of Ref. [3]). The origin of this large difference has to be investigated theoretically. We have the feeling that the fact that erbium orders near T_N with a modulated structure could be part of the reason. We notice that because $NdRh_2Si_2$ has quite a simple magnetic structure, the analysis of the critical behaviour of the damping should be not too hard. In fact it could be that before understanding the physics probed by μ SR in erbium (and thulium) one has to understand the

μ SR signal in simple antiferromagnets such as NdRh₂Si₂.

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References

- [1] M. Hagen, H.R. Child, J.A. Fernandez-Baca and J.L. Zarestky, *J. Phys.: Condens. Matter* **4** (1992) 8879.
- [2] R. de Renzi, G. Guidi, P. Podini, R. Tedeschi, C. Bucci and S.F.J. Cox, *Phys. Rev.* **B30** (1984) 186, *ibid* **B30** (1984) 197.
- [3] R. Wappling, O. Hartmann, S. Harris, E. Karlsson, G.M. Kalvius, L. Asch, A. Kratzer, P. Dalmas de Réotier and A. Yaouanc, *J. Mag. Mag. Mat.* **119** (1993) 123.
- [4] P. Dalmas de Réotier and A. Yaouanc, this conference.
- [5] B. Chevalier, J. Etourneau, P. Hagenmuller, S. Quezel and J. Rossat-Mignod, *J. Less Common Metals* **111** (1985) 161.
- [6] P. Dalmas de Réotier, J.P. Sanchez, A. Yaouanc, B. Chevalier, P. Chaudouët and R. Madar, *Hyperfine Interact.* **64** (1990) 457.
- [7] P. Dalmas de Réotier, A. Yaouanc, G.H. Eaton and C.A. Scott, *Hyperfine Interact.* **65** (1990) 1113.
- [8] P.C.M. Gubbens, A.A. Moolenaar, P. Dalmas de Réotier, A. Yaouanc, F. Kayzel, J.J.M. Franse, K. Prokes, C.E. Snel, P. Bonville, J.A. Hodges, P. Imbert and P. Pari, this conference.
- [9] P. Dalmas de Réotier, A. Yaouanc, P.C.M. Gubbens and B. Chevalier, this conference.
- [10] A. Yaouanc, P. Dalmas de Réotier, P.C.M. Gubbens, A.A. Moolenaar, A.A. Menovsky and C.E. Snel, this conference.
- [11] D. Beeman and P. Pincus, *Phys. Rev.* **166** (1968) 359.