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NMR of SmMn_2Ge_2 at high pressure

J.S. Lord^a, P.C. Riedi^{a,*}, Cz. Kapusta^b, K.H.J. Buschow^c

^aDepartment of Physics and Astronomy, University of St Andrews, St Andrews, Fife KY16 9SS, UK

^bDepartment of Solid State Physics, Faculty of Physics and Nuclear Techniques, University of Mining and Metallurgy, 30-059 Cracow, Poland

^cPhilips Research Laboratories, NL-5600 Eindhoven, The Netherlands

Abstract

The ^{147}Sm , ^{149}Sm and ^{55}Mn NMR of SmMn_2Ge_2 has been observed at 4.2 K at pressures up to 6.5 kbar. The Sm resonance frequencies appear to be insensitive to pressure but the Mn frequency decreases under pressure. The Mn resonance has also been observed at 77 K at atmospheric pressure, but disappears under a pressure of 1.6 kbar in agreement with the phase boundary between FM and AFM proposed earlier.

1. Introduction

At atmospheric pressure SmMn_2Ge_2 is a re-entrant ferromagnet [1–5]. The phase diagram is shown in Fig. 1, taken from Ref. [3]. There are some discrepancies as to the values for the temperature and pressure of the phase transitions (see Ref. [4] for a review), but the general appearance of Fig. 1 is not in dispute.

The crystal structure of SmMn_2Ge_2 is of the body-centred tetragonal BaAl_4 type [6] with the two crystallographically inequivalent Al sites occupied by Mn and Ge atoms. The atoms of each type lie on planes perpendicular to the c -axis with the sequence Mn–Ge–Sm–Ge–Mn. The intralayer Mn or Sm distance is much smaller than the interlayer distance.

The change from ferromagnetism to antiferromagnetism of SmMn_2Ge_2 below 150 K at atmospheric pressure was attributed [1] to the Mn–Mn spacing dropping below a critical distance for ferromagnetic interactions. (The Sm magnetisation is not thought to be significant at 150 K.) This view is supported by the positive slope of dT_N/dP [2,3], and the observation of a first order decrease in the lattice constant along the

a -axis in the antiferromagnetic region [2]. The reversion of SmMn_2Ge_2 to the ferromagnetic state below 100 K was attributed [1] to ferromagnetic ordering of the Sm causing the Mn movements to align ferromag-

Fig. 1. The phase diagram for SmMn_2Ge_2 , adapted from Ref. [3].

* Corresponding author.

Table 1
The NMR frequencies and effective fields for SmMn_2Ge_2

Nucleus	T (K)	ν (MHz)	B_e (T)	$(\partial \ln \nu / \partial P)$ (Mbar) $^{-1}$
^{55}Mn	273	144.7	−13.7	—
	77	189.0	−17.9	^a
	4.2	187.3	−17.7	−3.68(5)
^{149}Sm	4.2	475.6		
^{147}Sm	4.2	576.6	330	0.00(3)
Sm free ion			338	

^aFM to AFM transition.

netically. However, the entropy change at the first order transition [2] is only $(R/10)\ln 2$ which makes this mechanism doubtful and the present NMR results also do not support it.

At 4.2 K, the best value [2] for the moment per formula unit of SmMn_2Ge_2 is probably $3.8\mu_B$, although $4.18\mu_B$ was given in Ref. [1]. Assuming the Sm moment to have the free ion Sm^{3+} value of $0.71\mu_B$, and ferromagnetic coupling between Sm and Mn, leads to a Mn moment of $1.55\mu_B$. The moment per formula unit has decreased to $3.2\mu_B$ by 77 K and to $2.3\mu_B$ by 273 K. The Curie temperature is about 348 K.

The NMR experiments were carried out in a new 10–1000 MHz phase coherent swept frequency spin echo spectrometer that will be described elsewhere. The spectra were recorded by integrating the spin echo at each frequency as described in Ref. [7]. The NMR frequencies are tabulated in Table 1. The Sm NMR frequencies were converted to an effective field allowing for a hyperfine anomaly as discussed in Ref. [8].

The high pressure experiments were carried out in a Be–Cu cell. The pressure is applied to the liquid immersed sample at room temperature and can then be locked and cooled to low temperature. The pressure was measured using the resistance of a calibrated semiconductor transducer. The pressure at 4.2 K is about 3 kbar less than at room temperature so it is not possible to cool to an exactly chosen pressure. The transition from ferromagnetism to antiferromagnetism at 77 K in our sample of SmMn_2Ge_2 occurred for a pressure less than 1.6 kbar.

2. ^{55}Mn NMR

The ^{55}Mn NMR spectrum at atmospheric pressure and 4.2 K, shown in Fig. 2, consists of a single line

Fig. 2. The ^{55}Mn , ^{149}Sm and ^{147}Sm NMR spectra of SmMn_2Ge_2 at 4.2 K and atmospheric pressure.

some 3 MHz wide. There is no sign of quadrupole splitting (^{55}Mn , $I = 5/2$) of the NMR in the frequency swept spectrum, but the presence of an electric field gradient (EFG) is indicated by the modulation of the spin echo decay [9]. At 4.2 K the transverse relaxation time (T_2) is 400 μs and the modulation of the spin echo decay leads to a quadrupole splitting of 60 kHz, i.e. much less than the width of the inhomogeneously broadened line. At 77 K and above, the value of T_2 was so short, $\sim 5 \mu\text{s}$, that it was impossible to measure the modulation period of the echo.

Under pressure at 4.2 K the ^{55}Mn NMR frequency decreased (Table 1). Since the main contribution to the effective field at the ^{55}Mn nucleus arises from the contact interaction with the Mn moment, this suggests that the magnetisation of SmMn_2Ge_2 at 4.2 K decreases under pressure, supporting the view that wide spacing of the Mn atoms is essential for ferromagnetism in rare earth–Mn intermetallic compounds.

The ^{55}Mn NMR frequency at 77 K is higher than at 4.2 K although the magnetisation per formula unit has decreased from $3.8\mu_B$ to $3.2\mu_B$. This would suggest that the Mn moment has hardly changed between 4.2 K and 77 K, $T/T_c \approx 0.2$, while the Sm moment, $0.7\mu_B$ at 4.2 K, has largely collapsed. The proposal [1] that the Sm moment stabilises the ferromagnetic Mn interactions below 100 K may therefore be incorrect.

The ^{55}Mn NMR could not be observed under pressure at 77 K; a pressure of less than 1.6 kbar was sufficient to destroy the signal.

The ^{55}Mn NMR was also observed in the high temperature ferromagnetic phase at 273 K. The ratio of the ^{55}Mn NMR frequency at 77 K and 273 K (Table 1) is equal to that of the magnetisation reported in Ref. [2], confirming that the Sm does not contribute significantly to the magnetisation in this range.

3. Sm NMR

The ^{147}Sm and ^{149}Sm NMR exhibit the seven line quadrupole split spectrum expected for nuclear spin $7/2$ (Fig. 2). The ^{149}Sm quadrupole splitting was also observable as a modulation on the spin echo decay. It is unusual to be able to measure a quadrupole interaction by both methods in a given material.

The effective field at the Sm nucleus in SmMn_2Ge_2 is estimated to be 330 T, significantly less than the free Sm^{3+} ion value of 338 T (see Ref. [8] for a discussion of the conversion of Sm NMR frequencies to effective fields). The largest contribution to the Sm effective field comes from the orbital motion of the 4f electrons of the parent atom which will induce a field parallel to the magnetisation. The 8 T discrepancy between SmMn_2Ge_2 and the free Sm^{3+} ion value presumably arises from a transferred effective field from the Mn moments. However, under pressures up to 6.5 kbar no change was observed in the frequency of the Sm central NMR line to an accuracy of $\pm 0.03 \text{ Mbar}^{-1}$ in $(\partial \ln \nu / \partial P)$. Since the Mn moment, assumed to be proportional to the ^{55}Mn NMR frequency, has decreased by 2.4% by 6.5 kbar, a simple model would predict $\partial \ln \nu / \partial P \approx +0.08 \text{ Mbar}^{-1}$ for Sm. The decrease in the Mn moment under pressure must therefore be compensated by the decrease in the Mn–Sm distance.

The quadrupole splitting of the ^{147}Sm (^{149}Sm) NMR at 4.2 K, 8.6 (2.4) MHz, is significantly less than the

free ion values of 9.7 (2.8) MHz (see Ref. [8]), showing that the lattice contribution to the EFG has the opposite sign to the dominant 4f contribution. The value of $(\partial \ln \nu_Q / \partial P)$ was estimated to be less than 0.3 Mbar^{-1} which is consistent with our estimate of 0.1 Mbar^{-1} if only the lattice contribution changes with pressure.

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References

- [1] H. Fuji, T. Okamoto, T. Shigeoka and N. Iwata, *Solid State Commun.* 53 (1985) 715.
- [2] E.M. Gyorgy, B. Batlog, J.P. Remeika, R.B. van Dover, R.M. Felming, H.E. Blair, G.P. Espinosa, A.S. Cooper and R.G. Maines, *J. Appl. Phys.* 61 (1987) 4237.
- [3] M. Duraj, R. Duraj, A. Budkowski and A. Syztula, *Acta Magn. Suppl.* 87 (1987) 201.
- [4] A. Syztula and J. Leciejewicz, in: *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 12, eds. K.A. Gschneidner Jr. and L. Eyring (Elsevier, Amsterdam, 1989) p. 133.
- [5] R.B. van Dover, E.M. Gyorgy, R.J. Cava, J.J. Krajewski, R.J. Felder and W.F. Peck, *Phys. Rev. B* 47 (1993) 6134.
- [6] W. Rieger and E. Parthe, *Mh. Chem.* 100 (1969) 444.
- [7] T. Dumelow and P.C. Riedi, *Hyperfine Interactions* 35 (1987) 1061.
- [8] H. Figiel, Cz. Kapusta, N. Spiridis, G. Stoch, P.C. Riedi and M. Rosenberg, *J. Magn. Magn. Mater.* 104–107 (1992) 1198.
- [9] H. Abe, H. Yasuoka and A. Hirai, *J. Phys. Soc. Japan* 21 (1966) 77.