HYPERFINE MAGNETIC FIELD MEASUREMENTS IN FERROMAGNETIC CHALCOGENIDE SPINELS AND HEUSLER ALLOYS BY TDPAC TECHNIQUE

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In the year under review, we have started measurements of the hyperfine magnetic field in ferromagnetic spinels XCr_2Y_4 where X can be Cu, Zn, Cd, and Hg and Y can be S, Se, and Te. The magnetic moment is carried only by the Cr ions (μ=3 Bohr Magneton). The lattice parameter is about 10 Å. The spinel structure is shown in Fig. 1 where the B sites are exclusively occupied by Cr^{3+} ions, and the A sites by Cd or Cu ions. The Cr^{3+} ion moments are aligned parallel in ferromagnetic spinels through the intermediary of the chalcogen p electrons. The hyperfine field at Cd and Cu are brought about by the excess spin polarization electron density as a result of the super-transferred hyperfine interaction. The TDPAC technique offers a very powerful and convenient technique of introducing extremely dilute radioactive impurities and thus enabling the measurements of the hyperfine fields at a variety of probes. We have thus far measured the temperature variation of the hyperfine fields at ^{111}Cd in $CdCr_2S_4$ (T_c=84.5°K), $CdCr_2Se_4$ (T_c=129.5°K) and $Cu_{.99}Cd_{.01}Cr_2Te_4$ (T_c=365°K).

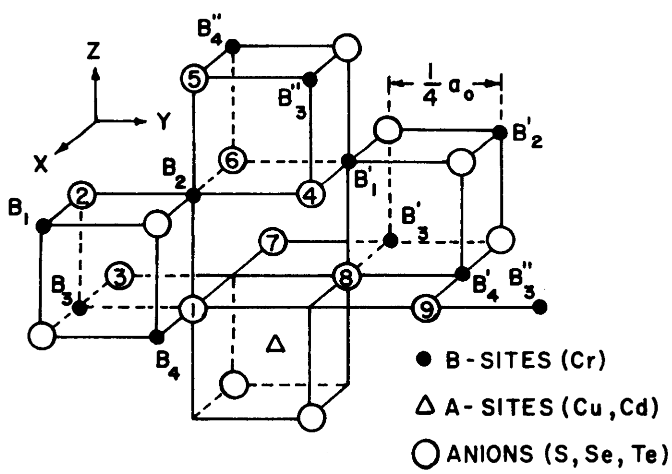

Figure 1. Positions of cations and anions in the spinel structure.

The studies of the hyperfine magnetic field in Heusler alloys have been continued. The studies have included the Heusler alloys of the type X_2MnY with $L2_1$ structure and of the type XMnY with Cl_b structure. The sign of the hyperfine field at the probe site is a very important piece of data. The sign of the field signifies the electron spin polarization direction at the probe site. The magnetic field at the probe site is positive if the field is parallel to the externally applied field, it is negative if it is anti-parallel.

The sign of the hyperfine magnetic field is determined as described below. The source in the Heusler alloy is placed in an external magnetic field of about 4 KG, the field being perpendicular to the plane of the detectors which are placed at 135°. The coincidence rate as a function of the angle between the detectors, θ, the time interval between the arrival of the start and the stop gamma-ray pulses,

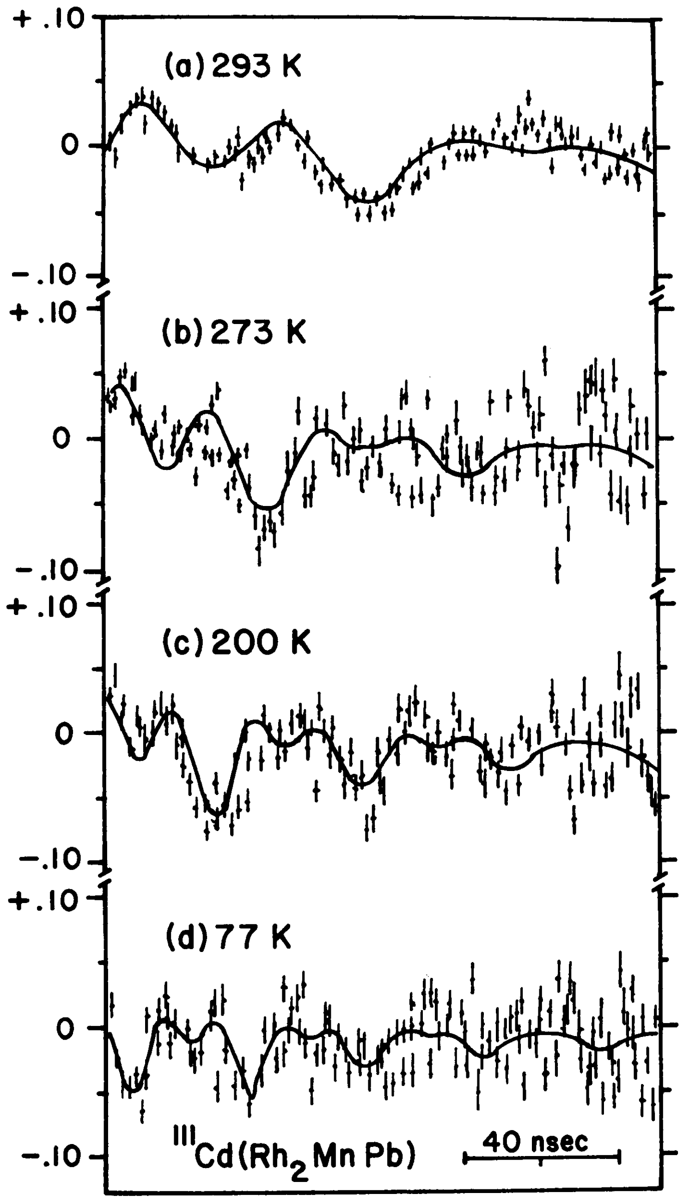

Figure 2. Perturbed angular correlation with Larmor oscillations for ^{99}Rh in Rh_2MnPb.

t, and the magnetic field, B, is given by

$$W(\theta,t,B)=\exp(-t/\tau)[1+a_2 \cos 2 (\theta-\omega_\ell t)]$$

where ω_ℓ= Larmor angular frequency

$$\omega_\ell = -g\mu_n B/\hbar \quad .$$

For $\theta = -135^o$, $a_2 = -0.2$, and a negative g-factor for ^{111}Cd, $W(-135^o,t,-B) = \exp(-t/\tau)(1+0.2 \sin 2 \omega_\ell t)$ and $W(-135^o,t,+B) = \exp(-t/\tau)(1-0.2 \sin 2 \omega_\ell t)$. The shape of the perturbed decay curve at t=0 determines the sign of the field. The sign of the hyperfine field has been determined for Ni_2MnGa, Ni_2MnIn, Cu_2MnIn and $Cu_{0.99}Cd_{0.01}Cr_2Te_4$. In Table I, the hyperfine magnetic fields at ^{111}Cd at different temperatures are given for Rh_2MnGe, Rh_2MnSn and Rh_2MnPb. The field values for Rh_2MnPb are derived from the data shown in Fig. 2. The hyperfine field normalized at T=77^{o}K is plotted against T/T_c in Fig. 3.

Table I. Hyperfine fields measured at ^{111}Cd sites in various alloys

Alloy	B(kG)	T(^{o}K)
Rh_2MnGe	188 ± 6	77
	160 ± 3	293
Rh_2MnSn	189 ± 5	77
	113 ± 5	293
	33 ± 3	373
Rh_2MnPb	143 ± 2	77
	114 ± 2	200
	84 ± 2	273
	53 ± 1	293

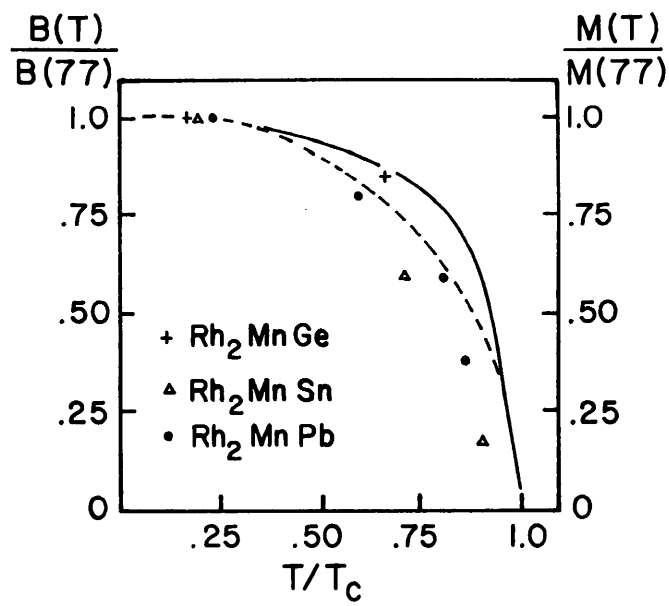

Figure 3. Hyperfine fields normalized at T=77^{o}K and plotted against T/Tc for ^{99}Rh in Rh_2MnGe, Rh_2MnSn and Rh_2MnPb.

Table II. Hyperfine fields measured at ^{111}Cd sites in various alloys

Alloy	B(kG)	T(^{o}K)
PtMnSb	166 $\pm$ 4	77
	161 $\pm$ 1	77
	153 $\pm$ 2	200
	138 $\pm$ 2	293
	125 $\pm$ 2	373
	95 $\pm$ 2	473
	76 $\pm$ 2	488
NiMnSb	213 $\pm$ 3	77
	-210.8$\pm$ 4.1	95
	208 $\pm$ 4	200
	194 $\pm$ 3	293
	-194.3$\pm$ 3.8	293
	191 $\pm$ 4	404
	169 $\pm$ 4	519
	125 $\pm$ 4	630
PdMnSb	260.9$\pm$ 4.5	90
	209.7$\pm$ 4.0	295

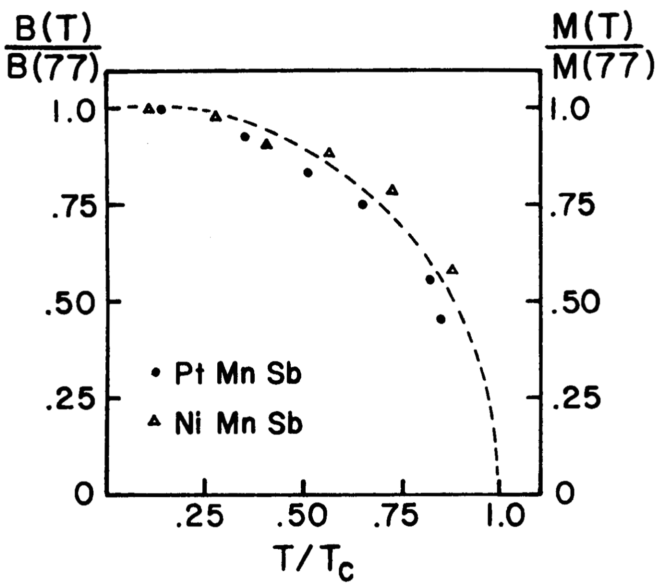

Figure 4. Brillouin function compared with the hyperfine fields measured for ^{111}Cd in PtMnSb and NiMnSb.

The experimental data deviate significantly from the Brillouin function for J=5/2. The hyperfine fields at ^{111}Cd in PtMnSb, NiMnSb and PdMnSb at various temperatures are given in Table II. The comparison with the Brillouin function similar to that in Fig. 2 is given in Fig. 4. The hyperfine field data for Ni_2MnGa, Ni_2MnIn, Cu_2MnIn, and Au_2MnIn are given in Table III. The comparison with the Brillouin function is given in Fig. 5. The hyperfine field direction at ^{111}Cd in Ni_2MnGa is shown to be negative.

Our experimental data for $^{111}In(CdCr_2Se_4)$ at 4.2^{o}K, 77^{o}K, and 293^{o}K yielded the hyperfine field values given in Table IV and was also shown to be positive. These data confirm the results of NMR studies of these spinels.

Table III. Hyperfine Magnetic Field at ^{111}Cd sites in Heusler Alloys X_2MnIn and X_2MnGa

Alloys	T_c (^{o}K)	B(KG)	T(^{o}K)
Ni_2MnGa	379	226±3	77
		197±4	195
		162±4	273
		147±2	293
		93±3	333
Ni_2MnIn	323	158±1	77
		136±2	195
		93±1	273
		71±1	293
Cu_2MnIn	500	216±1	77
		207±2	195
		191±2	293
		164±3	380
Au_2MnIn	140	155±3	77

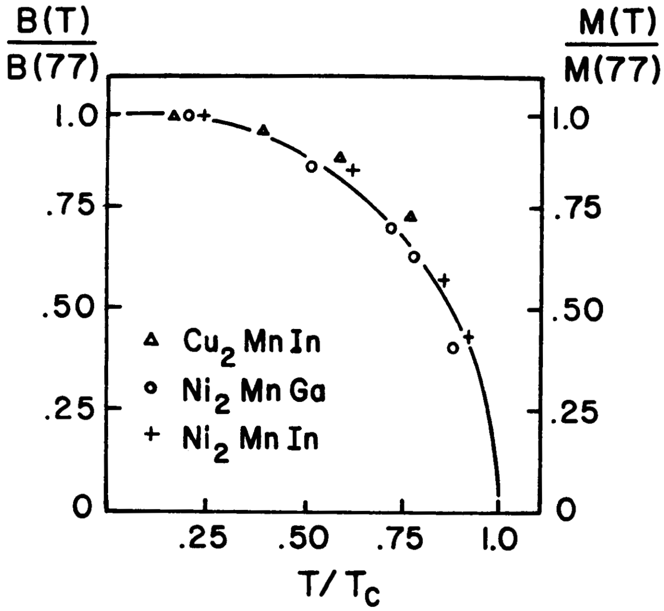

Figure 5. Comparison of the Brillouin function with the hyperfine fields measured for [111]*In in* Cu_2MnIn, Ni_2MnGa *and* Ni_2MnIn.

Table IV. Hyperfine Magnetic Field at [111]Cd Probe in Chalcogenide spinels

Alloys	T_c (°K)	B(KG)	T(°K)
$CdCr_2S_4$	84.5	85.5±1	77
		168 ±2	4.2
$CdCr_2Se_4$	129.5	104 ±1	77
		132 ±1	4.2
$Cu_{.99}Cd_{.01}Cr_2Te_4$	365	98.5 ±1	77
		79 ±1	195
		44.5 ±1	293