HYPERFINE MAGNETIC FIELD MEASUREMENT IN HEUSLER ALLOYS BY TDPAC TECHNIQUE

S. Jha,* Naser Salen,* M. Elfazani,* A. Budrys,* R. Rolfes,*
Glenn M. Julian,† R. Black,† J.W. Blue,** D.C. Liu,** and T.E. Ward

Heusler alloys X_2 Mn Y and X Mn Y (where X can be Co, Ni, Cu, Ru, Pd, Ir, Pt and Au and Y can be a s-p element like Al, Ga, Ge, Cd, In, Sn, Sb, Te, I, and Pb) are very attractive systems where the theories of the occurrence of magnetic order and the sign and the magnitude of the hyperfine magnetic field can be severely tested. In these cubic alloys, the magnetic moment is carried primarily by the Mn ions (about 4 Bohr magnetons). They order in L 2_1 structure when the composition is X_2 Mn Y but in C 1_b structure when the composition is X Mn Y. The magnetic interaction in these alloys is considered to be of long range character occurring through the conduction electron polarization.

In recent years, a lot of hyperfine fields have been measured at impurity sites in Fe, Co, Ni and Gd and at various sites in Heusler alloys. There is a systematic trend of the magnitude and the sign of the hyperfine fields at the impurity sites. We have been measuring systematically the hyperfine fields in Heusler alloys at ^{99}Ru, ^{100}Pd, ^{111}Cd, ^{119}Sn, ^{189}Os and ^{191}Ir by TDPAC technique using 16-d ^{99}Rh, 4-d ^{100}Pd and 3-d ^{111}In and by Mossbauer technique using ^{119m}Sn, 13-d ^{189}Ir and 3-d ^{191}Pt. In this report, the TDPAC experiments and the results are described.

The Heusler alloys Rh_2 Mn Y and Rh Mn Y have been studied for the measurement of the hyperfine fields at Ru by using ^{99}Rh and for the measurement of the hyperfine field at ^{111}Cd (which presumably occupies the Y site) by using ^{111}In. 99.8% purity rhodium metal powder was bombarded with about 60 MeV protons to produce ^{103}Rh (p, 5 n) ^{99}Pd--^{99}Rh--^{99}Ru. The alloys Rh_2Mn Y and Rh MnY were produced by mixing soichiometric amounts of radioactive rhodium metal powder and Mn and "Y" metal powders, sealed in a quartz tube in an argon atmosphere at 7" pressure. The samples were heated at 200°C for 20 hrs, then at 300°C for 24 hrs and at 850°C for 30 hrs. It was then slow-cooled, pulverized, sealed in an evacuated quartz tube, annealed for 90 hrs at 950°C and finally slow-cooled. For the studies of alloys Pd_2Mn Y, ^{99}Rh was produced in palladium metal target by bombarding Pd metal target with about 90 MeV protons to produce ^{99}Rh. By mixing this target material with proper amounts of Mn and Sb, the Heusler alloys were prepared by standard methods. For the measurements of the hyperfine fields at Cd sites, ^{111}In was produced in In metal by the bombardment with 30 MeV protons. The radioactive indium metal replaced 2 atomic % of the s-p element in the Heusler alloy. X-ray powder diffraction spectra of the alloys were recorded; the appearance of appropriate peaks showed that the ordered alloy had been formed.

The hyperfine magnetic fields were determined by the Time Differential Perturbed Angular Correlation Technique (TDPAC). Measurement of the field at Ru utilized the decay of 16-day ^{99}Rh with the emission of two cascade gamma-rays of energy 354 keV and 90 keV through the 90 keV intermediate state of half-life 20.7 nsec, spin 3/2 and the magnetic moment -0.284 nm. The measurement of the field at the Cd site utilized the decay of 2.8-day ^{111}In having cascade gamma-rays of energy 173 keV and 247 keV through the 247 keV intermediate state of half-life 84 nsec,spin 5/2 and the magnetic moment of -0.7655 nm. The TDPAC spectra were recorded using two NaI(Tl) detectors at 180° with RCA 8575 photomultipliers, a standard slow-fast coincidence system and Time to Amplitude converter and a multichannel analyzer.

The angular correlation function for the randomly

oriented magnetic domains can be written as

$$W(\theta) = 1 + A_2G_2(t)P(\cos\theta)$$

where $G_2(t) = (1/5)(1 + 2\cos\omega t + 2\cos 2\omega t)$

and ω = Larmor precession frequency = $\mu B/I\hbar$.

The experimental time spectra were fitted with the function

$$N(t) = B(t) + C_2 \exp(-\lambda t) W'(180^o)$$

where $B(t) = C_1 + C_6 t$

$$W'(180^o) = 1 + G_2'(t)$$

$$= 1 + C_5\,1 + 2\exp(-C_7 t)\cos(C_4 t) + 2\exp(-2C_7 t)\cos(2C_4 t)$$

$$t \propto (\text{channel} - C_3)$$

The C_i's are the 7 adjustable constants fitted by a Gauss-Newton non-linear least-squares technique. The exponential damping of the perturbation is included to allow for a possible Lorentzian spread in the precession frequency. After removing from the experimental time spectrum, the fitted background, and the exponential decay of the intermediate state, the results are presented in the form of plots of the reduced data and the fitted function $A_2G_2'(t)$.

The time spectra for ^{99}Ru probe at the Rh site in Rh MnGe yield $A_2G_2'(t)$ are presented in Figure 1. The data were recorded at 77K, 293K and 355K.

The time spectra for the ^{99}Ru probe at the Rh site in Rh MnSn yield $A_2G_2'(t)$ are presented in Figure 2. The data were recorded at 293K and 355K.

The time spectra for the ^{99}Ru probe at the Rh site in RhMnSb and PdMnSb give $A_2G_2'(t)$ are presented in Figures 3 and 4. The data were fitted at room temperature.

The results of the hyperfine field measurements made by us are summarized in Table 1.

*University of Cincinnati, Cincinnati, OH 45221

†Miami University, Oxford, OH 45056

**NASA-Lewis Research Center, Cleveland, OH 44135

Table 1.

Alloy	Probe	Site	T(K)	B(K Gauss)
Rh MnGe	Ru	Rh	77	195 ± 11
			293	126 ± 4
			355	49 ± 4
	Cd	Ge	77	245 ± 10
			293	160 ± 3
Rh MnSn	Ru	Rh	293	137 ± 2
			355	37 ± 6
	Cd	Sn	77	189 ± 5
			293	113 ± 5
			373	33 ± 3
RhMnSb	Ru	Rh	293	276 ± 5
PdMnSb	Ru	Pd	293	274 ± 5

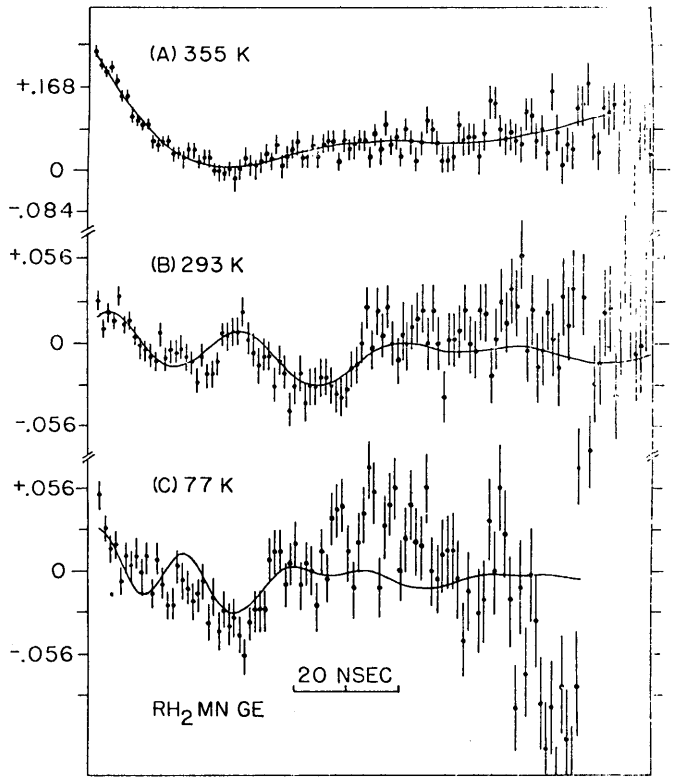

Figure 1.

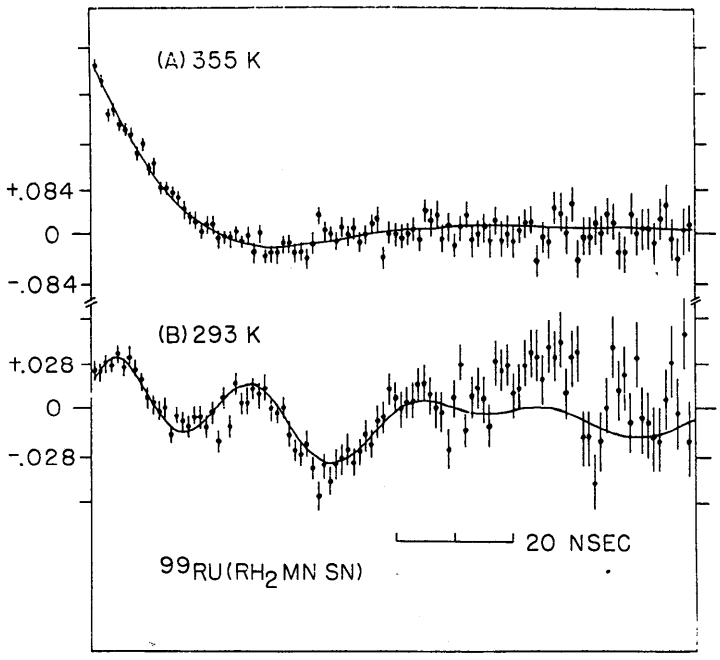

Figure 2.

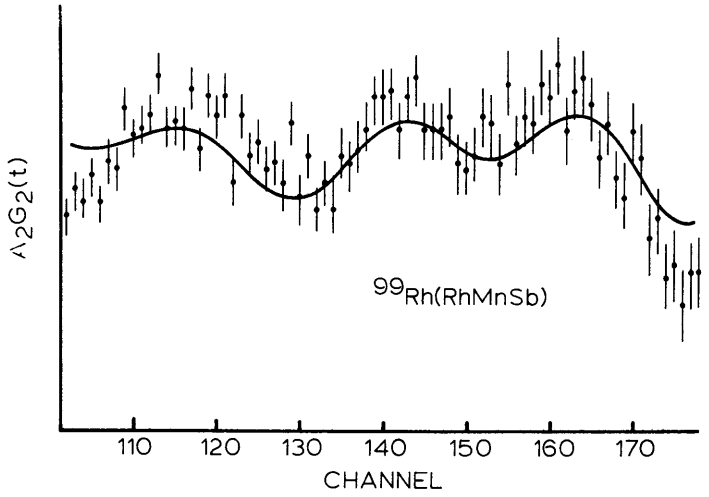

Figure 3.

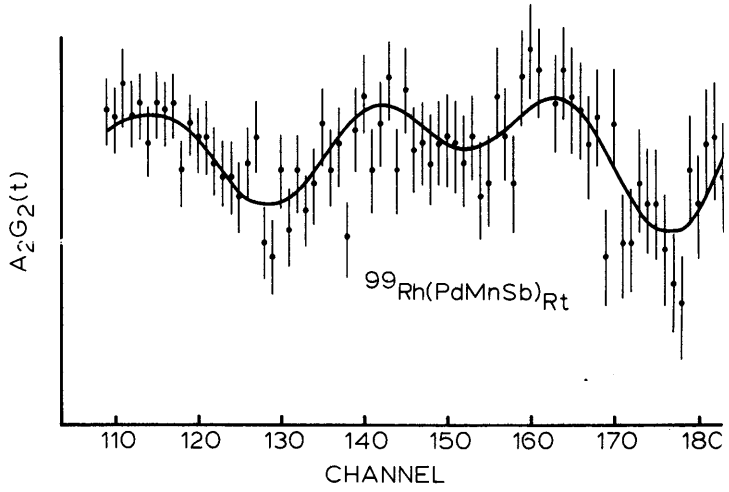

Figure 4.