

Anisotropy of the magnetic hyperfine interaction for Sn-119 impurity atoms in SmAl₂ ferromagnet

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A pronounced anisotropy of the hyperfine interaction for ¹¹⁹Sn impurity atoms in SmAl₂ has been detected by Mössbauer spectroscopy. The magnetic hyperfine fields for two orientations of the magnetization with respect to the local symmetry axis (at angles of 0 and 70°) are 16.3 and 18.9 T, respectively, at a temperature of 5 K. This anisotropy reflects the nonspherical distribution of 4*f* electrons of the samarium ion.

The ions of rare-earth metals with a nonvanishing orbital angular momentum have a spatially anisotropic distribution of 4*f* electrons. This circumstance has many important consequences for the properties of rare-earth magnetic materials (the magnetic anisotropy, the giant magnetostriction, and the anisotropy of the exchange interaction). The nonspherical distribution of 4*f* electrons may also be manifested as an anisotropy of the hyperfine interaction. This anisotropy is particularly interesting in rare-earth intermetallic compounds for nonmagnetic atoms (i.e., for atoms having a zero intrinsic magnetic moment). In this case the hyperfine interaction is determined by the magnetic surroundings, so that the parameters of the hyperfine interaction incorporate information on the interatomic interaction and the mechanisms for the transfer of spin density from the magnetic (rare-earth) ions to the nonmagnetic atom. There has apparently been no previous study of the effect of the nonspherical distribution of 4*f* electrons on the hyperfine interaction for non-magnetic atoms.

In the present experiments we observed a pronounced anisotropy of the hyperfine interaction for ¹¹⁹Sn impurity atoms replacing Al atoms in the ferromagnetic intermetallic compound SmAl₂. The parameters of the hyperfine interaction were measured by Mössbauer spectroscopy with a polycrystalline SmAl₂ sample containing 0.6 at.% of tin enriched to 92% in the isotope ¹¹⁹Sn. The alloy was produced by melting in an arc furnace in an atmosphere of pure argon with annealing in a vacuum at 900 °C for 8 h. For improved resolution, we used a resonant CaSnO₃ γ detector. The details of the measurement technique and the procedure for processing the spectra are described in Refs. 1 and 2. The aluminum sites in SmAl₂ have an orthorhombic symmetry with a threefold axis directed along one of the symmetry axes of the tetrahedra which center the octants of the cubic lattice of Sm³⁺ ions. All the aluminum sites are structurally equivalent. An easy-magnetization axis runs along the [111] axis.³ Two groups of aluminum sites arise (*a* and *b* sites, with a population ratio of 1:3), for which the angles between the threefold axis and the magnetization are 0° and 70°32', respectively. As a result, both the anisotropic contribution to the magnetic hyperfine field and the quadrupole shift of the components of the hyperfine structure^{1,3} are different for the *a* and

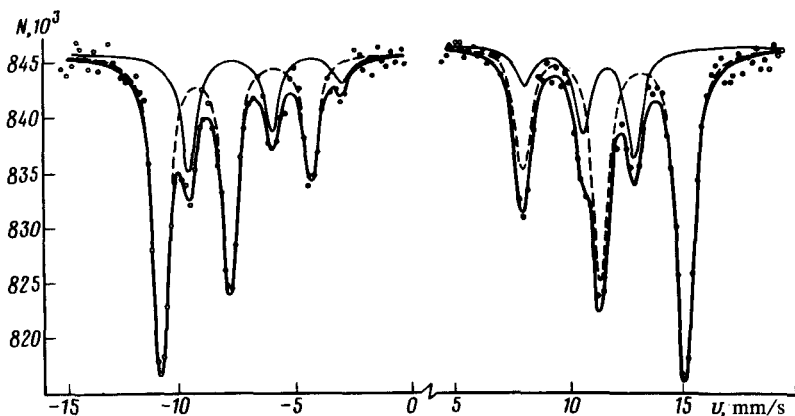


FIG. 1. Mössbauer absorption spectrum for ^{119}Sn impurity atoms in SmAl_2 , measured at 5 K. The thin solid curves and dashed curves are partial spectra corresponding to Sn atoms at a and b sites.

b sites. We thus have a tool for studying the anisotropy of the hyperfine interactions with a polycrystalline sample without imposing an external magnetic field. The magnetic moment of the Sm^{3+} ion in SmAl_2 is very small ($\sim 0.2\mu_B$), so that the dipole contribution to the magnetic hyperfine interaction does not exceed⁴ 0.1 T.

Figure 1 shows the absorption spectrum measured at 5 K. The components of the hyperfine structure are well resolved, so that the spectrum can be interpreted unambiguously as a superposition of two sextets with a 1:3 intensity ratio (Sn atoms replacing Al atoms at a and b sites). The magnetic hyperfine fields (B), the quadrupole shifts (Δ) of the components of the hyperfine structure, and the isomer shifts (IS) are found for the a and b sites to be $B(a) = 16.3 \pm 0.1$ T, $\Delta(a) = -0.31 \pm 0.03$ mm/s, $IS(a) = 1.92 \pm 0.04$ mm/s, $B(b) = 18.9 \pm 0.08$ T, $\Delta(b) = 0.21 \pm 0.05$ mm/s, and $IS(b) = 1.93 \pm 0.02$ mm/s. (The isomer shifts are given with respect to the CaSnO_3 source at room temperature.) Measurements of the shift of the components in an external magnetic field showed that the magnetic hyperfine fields are positive (they are directed parallel to the total magnetic moment of the samarium ion and antiparallel to its spin moment).

The large difference between $B(a)$ and $B(b)$ corresponds to a pronounced anisotropy of the magnetic hyperfine interaction which results from the interaction of the Sn atom with the nonspherical distribution of magnetic electrons of the Sm^{3+} ion. It may be that the $4f$ electrons of the Sm^{3+} ion have a greater dimension along the direction perpendicular to the moment of the ion and a smaller dimension along the direction of the moment. In this case, the large value of B for the Sn atoms at the b sites corresponds to a smaller effective distance between the Sn atom and the magnetic electrons of the Sm^{3+} ion. This correlation between the hyperfine field and the distance agrees with the radial dependence found for the hyperfine interaction of Sn impurity atoms in intermetallic compounds of gadolinium.² The constant of the quadrupole interaction, e^2qQ , is also very anisotropic. The quadrupole shifts Δ for the a and b sites are¹ $\Delta(a) = e^2qQ/4$ and $\Delta(b) = -e^2qQ/12$, from which we find $e^2qQ(a) = -1.2 \pm 0.2$ mm/s and $e^2qQ(b) = -2.5 \pm 0.6$ mm/s. We see that the decrease in the effective

distance between the Sn atom and the 4 *f* electrons is accompanied by a greater deformation of the valence orbitals of the Sn atom. This deformation does not affect the *s* component of the electron wave function, since the isomer shifts are identical for the *a* and *b* sites.

¹N. N. Delyagin, V. I. Nesterov, and S. I. Reĭman, Zh. Eksp. Teor. Fiz. **84**, 1580 (1983) [Sov. Phys. JETP **57**, 922 (1983)].

²N. N. Delyagin, G. T. Mudzhiri, V. I. Nesterov, and S. I. Reĭman, Zh. Eksp. Teor. Fiz. **86**, 1016 (1984) [Sov. Phys. JETP, to be published].

³N. Kaplan, E. Dormann, K. H. J. Buschow, and D. Lebenbaum, Phys. Rev. **B7**, 40 (1973).

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