Letters to the Editor

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Microwave Resonance Absorption in Gadolinium Metal*

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MICROWAVE resonance absorption in gadolinium metal has been measured near 9000 and 24 000 Mc/sec in the ferromagnetic and paramagnetic regions. Gadolinium is known to exhibit a saturation magnetization[1] corresponding closely (±2 percent) to the value expected for an ^8S state, where the magnetic moment of each atom is due to the seven electrons in the $4f$ shell. It is therefore likely, as Van Vleck[2] has emphasized, that Gd is a good realization of the atomic model of a ferromagnet, in contrast to the ferromagnetic metals of the iron group, all of which show saturation magnetizations which cannot be explained on such a simple basis. From this point of view, we wished to determine how closely the g value corresponds to the value for free electron spin, as expected for a half-filled shell. Our results suggest that there may be spin-orbit coupling effects, perhaps between the spin of $4f^7$ shell and the orbit of the $5d$ electron, which partly spoil the purity of the assumed ^8S ionic state.

An annealed circular disk of polycrystalline Gd, 2.3 cm in diameter and 0.04 cm thick, was used in these experiments. The sample contained no more than 0.1 percent of other rare earth elements. Absorption measurements were made by clamping the sample behind a hole of area 0.049 cm² drilled into the end wall of a resonant cavity, so that the sample effectively forms a small part of this wall. Figure 1 shows a typical resonance curve.

Results in the 9000 Mc/sec range were consistent with the 24 000 Mc/sec results, but because of the greater accuracy of the measurements at the higher frequency, only the latter will be given. Measurements were made in the temperature range between −196°C and +105.5°C. The Curie temperature is 16°C, according to Trombe. Figure 2 summarizes the results at 24.30×10^3 Mc/sec for the positions of maximum absorption *vs* temperature. The principal cause of the shift of the peak position in going from the paramagnetic to the ferromagnetic region is the increase in magnetization of the sample. The individual absorption curves in the paramagnetic range exhibit the typical shape of resonance curves in metals, as found by Yager[3] and Bloembergen[4] in the case of supermalloy and nickel. The width of the absorption curves in the paramagnetic region is approximately 1000 oersteds at the half-power points. Below 20°C the width increases rapidly, and below 0°C the width is so great that no estimate can be made of the width, using external fields from 0 to 10 000 oersteds. The cause of the extreme width in the ferromagnetic region is not understood, but may be associated with a high crystalline anisotropy energy and polycrystalline broadening. The value of the magnetization in the ferromagnetic range was obtained from unpublished data of Elliott, Legvold, and Spedding.

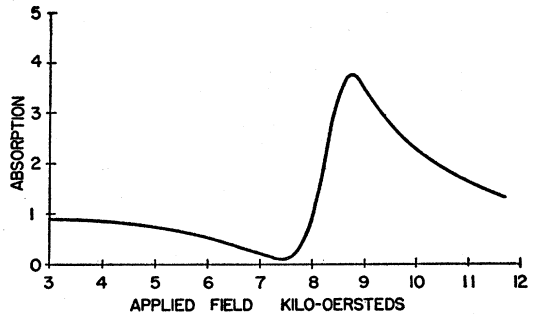

FIG. 1. Gadolinium metal resonance absorption at 24.3×10^3 Mc/sec, $T=105.5$°C.

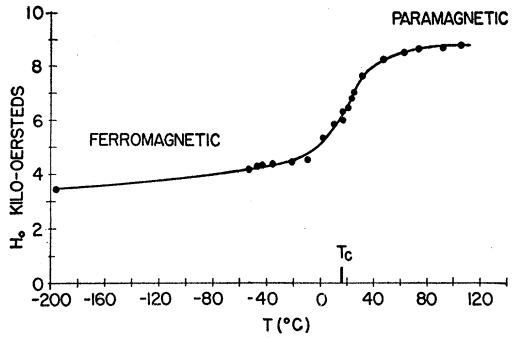

FIG. 2. Gadolinium metal peak position *vs* temperature, at 24.3×10^3 Mc/sec.

The g factor obtained in the paramagnetic region is 1.95±0.03, taking into account shifts in the peak position due to demagnetizing factors and relaxation effects, as well as the effect of varying eddy current losses. In the ferromagnetic region the extreme breadth of the absorption curve prevents accurate determination of the g value. However, we have made calculations of the ferromagnetic g value, ignoring possible shifts in peak positions arising from relaxation effects. These calculations lead to a ferromagnetic g value of 1.94. A limit of uncertainty cannot be assigned to this value because of the extreme breadth of the absorption curves, but the g value is not inconsistent with that in the paramagnetic range.

Our results are to be compared with recent unpublished results of Elliott, Legvold, and Spedding on the saturation magnetization extrapolated to 0°K and infinite applied field. The g value obtained from this value of saturation magnetization is 1.96.

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Electronic Structure of the Germanium Crystal

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THE method of orthogonalized plane waves,[1] recently applied to the diamond crystal,[2] has been used to study the energy band structure of the germanium crystal. The calculation is based on the usual one-electron approximation. A crystal model constructed from isolated atoms $[Ge(4s)^1(4p)^3]$ arranged as a germanium lattice was used to determine the Coulomb potential. The constituent atomic wave functions were taken from the self-consistent field calculations for Ge.[3] The effect of exchange was not considered due to the complexity of available approximate treatments.