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PARAMAGNETIC RESONANCE IN METALLIC EUROPIUM AND INTERMETALLIC COMPOUNDS

Martin Peter and B. T. Matthias

Bell Telephone Laboratories, Murray Hill, New Jersey

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Kip¹ et al. have reported spin paramagnetic resonance in Gd metal which is due to the Gd ions in the $^8S_{7/2}$ state. Bozorth and Van Vleck² have recently concluded from magnetic susceptibility measurements that europium must also occur in the $^8S_{7/2}$ state. This implies, however, that europium, unlike the other rare earths, is divalent in its cubic body-centered form. If this assignment is correct and if the ionic spin relaxation time in europium is not excessive, then a paramagnetic resonance analogous to the one observed in gadolinium must be present. In a similar way paramagnetic resonance will be indicative of the valence of Eu in intermetallic compounds. In this Letter we report the result of resonance experiments in Eu metal and the compounds EuIr_2 and GdIr_2 .

The experiments were carried out in the millimeter wave spectrometer described elsewhere.³ This instrument uses no resonant cavity; instead, the europium was introduced as part of the waveguide wall, and the intermetallic compounds, which were only available as powders, were fastened to the walls with paraffin. Because of the complex geometry and a high standing-wave ratio, we cannot predict the exact absorption line shape, using Bloembergen's⁴ theory; however, the line shape is still, for $\chi \ll 1$, a linear superposition of χ' and χ'' , and since, for $\Delta H/H_0 \ll 1$, χ' and χ'' have simple symmetry properties around the resonance field H_0 , we can determine this field to a fraction of the half-power linewidth ΔH .

Figure 1 shows the resonance line observed in europium metal. It occurs at $g = 1.985 \pm 0.015$.

The linewidth $\Delta H = 1300$ gauss is approximately constant between room temperature and 120°K where it broadens and then disappears. The europium metal was produced by Research Chemicals and was said to contain no significant amount of paramagnetic impurities. The integrated strength of the line is approximately the same as the one found in gadolinium metal at 100°C . Efforts were made to keep the metal surface bright; however, if the surface was allowed to oxidize, the line did not change its appearance. Strength and its independence of surface state and the temperature behavior are evidence that this line is indeed due to europium metal.

The susceptibility measurements of Bozorth and Van Vleck find an anomaly (probably antiferromagnetic) in the europium susceptibility at 90°K . From the work of Maxwell and McGuire⁵ it is known that line broadening sets in considerably above the transition point and, hence, we

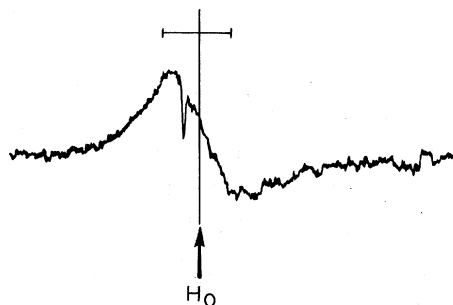


FIG. 1. Paramagnetic resonance of europium metal. Recording made at 51.0 kMc/sec. H_0 indicates the field for resonance.

attribute the temperature behavior of the line-width to this transition.

The resonance line with a g factor of 1.985 cannot be explained from the behavior of Eu^{+++} , which is in the $4f^6$ configuration with the ground state 7F_0 . The first excited state, 7F_1 , which in the free ion is 480°K above the ground state, would give a resonance with a Landé g factor of $g=9/8$. The paramagnetic resonance experiment confirms, therefore, the metallurgical⁶ and magnetic² evidence for the divalent state of metallic europium. Below the antiferromagnetic anomaly (which is also borne out by electrical conductivity measurements on europium wire reported by Olsen⁷) the magnetic behavior is at present not well understood. Unlike the case of an antiferromagnet, the magnetization continues to increase. But we found no further magnetic resonance even at helium temperature. With the present apparatus, we could, however, not have seen a resonance with a g value smaller than 1.3. It is, therefore, not impossible that the resonance could have appeared at lower frequencies. If, on the other hand, this anomalous magnetic behavior were of similar origin to the one reported for cerium⁸ (promotion of $4f$ electron into the $5d$ band), then observation of a resonance would be difficult because of the fast relaxation of the d electrons.

The intermetallic compound EuIr_2 crystallizes in the cubic Laves phase (C15) and from its lattice constant Zachariasen⁹ concluded that Eu is here indeed in its trivalent state. Though it may become ferromagnetic, its saturation moment is

almost vanishing.¹⁰ In agreement with this evidence we have seen no paramagnetic resonance in this compound. GdIr_2 , on the other hand, which is isomorphous with EuIr_2 and of course also trivalent, shows an absorption due to Gd which is 1500 gauss wide. This resonance increases in strength with decreasing temperature and has been followed to below the Curie point, where the resonance broadens to a point where observation is no longer feasible.

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DESTRUCTION OF DIATOMIC BONDS BY PRESSURE*

B. J. Alder and R. H. Christian[†]

Lawrence Radiation Laboratory, University of California, Livermore, California

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The pressure necessary to destroy the directional character of chemical bonds has been discussed theoretically in connection with hydrogen.^{1,2} This phenomenon has now been experimentally observed in iodine as a first-order phase transition, since the delocalization of the electrons causes the diatomic molecular crystal to be converted into a monatomic metal. The results for iodine can be used to evaluate the predictions made for hydrogen.

The experiments were carried out by standard

single-shock experiments³ on polycrystalline iodine at an initial density within 1% of the single-crystal density. The measured shock velocity, u_s , versus particle velocity, u_p , is shown in Fig. 1. The experiments again conform within the accuracy of the data to the empirical linear relation between these two quantities. Moreover, the line extrapolates properly to the experimental sound speed (1.35 mm/ μ sec) at zero particle velocity. The square points are from slightly less accurate experiments. The