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HYPERFINE FIELDS AT 3d IMPURITIES IN FERROMAGNETIC GdZn AND GdCd

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Abstract. - The hyperfine (hf) fields at 3d impurities in ferromagnetic CsCl type compounds GdZn and GdCd have been measured by NMR method at 4.2 K. The hf field values suggest nearly zero moments on Sc, Co and Ni and a finite moment on Mn, which is antiparallel to the host Gd moments.

Hyperfine (hf) fields at impurities in ferromagnetic metals can give information about the electronic structures of the host and impurities and the formation of local moments on the impurity ions [1, 2]. In transition metal hosts of iron and nickel the hf fields data have been available from various experimental methods [3]. In rare earth metal hosts such data on hf fields at impurities are not necessarily enough, although the general trends are clear [4, 5]. This is partly due to the very low solubility of impurity into rare earth metals. The hf fields at 3d impurities in ferromagnetic compounds GdZn (Tc = 269 K [6]) and GdCd (Tc = 268 K [6]) have been measured by NMR method in order to obtain the systematics of hf fields at impurities and the information about the formation of local moments on the impurity ions in rare earth metallic hosts. GdZn and GdCd have the cubic CsCl type structure, in which 3d impurities except Sc are expected to occupy primarily the Zn(Cd) sites with a considerable solubility. Their simple crystal structure makes it easy to interpret the experimental data.

The samples were prepared by melting appropriate amounts of Gd, Zn(Cd) and 1 at.% impurity metal (Sc, V, Mn, Fe, Co, Ni and Cu) in enclosed tantalum crucibles under argon atmosphere at 1 250 °C and by quenching the crucibles into water. As Fe and Ni impurities enriched 57Fe and 61Ni isotopes were used. NMR measurements were made on powdered samples by pulsed NMR method at 4.2 K.

Table I. – NMR frequencies and hyperfine fields of impurity nuclei in GdZn and GdCd.

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>GdZn ν (MHz)</th>
<th>GdZn H_i (kOe)</th>
<th>GdCd ν (MHz)</th>
<th>GdCd H_i (kOe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55Sc</td>
<td>40.0</td>
<td>38.7</td>
<td>41.6</td>
<td>40.2</td>
</tr>
<tr>
<td>55Mn</td>
<td>170.9</td>
<td>+162.8</td>
<td>182.6</td>
<td>+173.9</td>
</tr>
<tr>
<td>59Co</td>
<td>102.6</td>
<td>-102.3</td>
<td>102.0</td>
<td>-102.0</td>
</tr>
<tr>
<td>61Ni</td>
<td></td>
<td></td>
<td>44.5</td>
<td>117</td>
</tr>
<tr>
<td>63Cu</td>
<td>148.1</td>
<td>131</td>
<td>142</td>
<td>126</td>
</tr>
<tr>
<td>65Cu</td>
<td>158.5</td>
<td>131</td>
<td>152</td>
<td>126</td>
</tr>
<tr>
<td>67Zn</td>
<td>46.8</td>
<td>-176</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The lineshapes of the 55Mn and 63,65Cu NMR in GdZn are shown, as typical examples, in figure 1. The NMR frequencies and the hf fields H_i are listed in table I, where the result for 67Zn in GdZn is also given. The 61Ni NMR in GdZn could not be observed, because it lies behind the strong 67Zn NMR line as expected from the 67Ni NMR in GdCd. For V and Fe impurities the NMR observation was unsuccessful in both compounds. The positive and negative signs of H_i for 55Mn and 59Co were obtained by measuring magnetic field dependences of the NMR frequencies. In figure 2

Fig. 1. – NMR spectra of the 55Mn and 63,65Cu impurity nuclei in GdZn at 4.2 K.

Fig. 2. – Systematics of the hyperfine fields at 3d impurities in GdZn and GdCd, which is compared with that in Gd metal. The dashed curve represents the conduction electron polarization fields H_{ce} in GdZn.
the results of $H_i$ for the 3d series are shown, in comparison with the data in the Gd host [4, 5]. Here, the signs of $H_i$ for the impurities except Mn and Co are assumed to be negative. The trend of $H_i$ in GdZn(Cd) is very similar to that in the Gd host, and, for example, the $^{55}$Mn hf fields are positive and nearly equal in both GdZn and Gd metal.

The hf field at an impurity nucleus consists of the field due to the local moment on the impurity $H_{\text{loc}}$, the conduction electron polarization field due to neighbouring Gd moments $H_{\text{ce}}$ and the Lorentz field $H_L$, i.e.,

$$H_i = H_{\text{loc}} + H_{\text{ce}} + H_L. \quad (1)$$

The Lorentz field $H_L = 4\pi M / 3$ is estimated as $+6.3$ and $5.6$ kOe for GdZn and GdCd, respectively. The usual procedure for estimating $H_{\text{ce}}$ is to obtain the hf fields at nonmagnetic Sc and Cu impurities, which are at the beginning and end of the impurity series, and interpolate them through the series [4]. Such an interpolation of $H_{\text{ce}}$ cannot, however, be adopted in the present system, because Sc and Cu impurities are expected to occupy the Gd and Zn(Cd) sites, respectively, in the GdZn(Cd) lattice. In the table I we find that the Cu hf field is larger in GdZn than in GdCd, while the Sc hf field is larger in GdCd. This difference is due to that in the site occupations of Cu and Sc impurities.

The conduction electron polarization field $H_{\text{ce}}$ is phenomenologically given by

$$H_{\text{ce}} = pH_{\text{as}}, \quad (2)$$

where $H_{\text{as}}$ is the atomic ns electron hf field and $p$ is a parameter representing the spin polarization. Using the values of $H_{\text{as}}$ calculated by Campbell [7], after the correction for $H_L$, the values of $p$ for $^{63}$Cu and $^{45}$Sc are respectively estimated as $-0.051$ and $-0.058$ in GdZn and $-0.049$ and $-0.059$ in GdCd. The values of $p$ for Cu are nearly equal to $-0.052$ for $^{67}$Zn in GdZn [6] and $-0.050$ for $^{111}$Cd in GdCd [6]. The difference between the $p$ values for Cu and Sc is partly due to that in the site occupations of these impurities. In figure 2 the dashed curve represents the values of $H_{\text{ce}} = pH_{\text{as}}$ calculated by assuming the same value of $p = -0.051$ for $^{63}$Cu in GdZn through the 3d series and using Campbell's values of $H_{\text{as}}$ [7]. Using these values of $H_{\text{ce}}$ in equation (1), the values of $H_{\text{loc}}$ are estimated and are listed, together with those of $H_{\text{ce}}$ in table II, where the results for GdCd are obtained with $p = -0.049$. The values of $H_{\text{loc}}$ are large and positive for Mn, but nearly zero for Co and Ni. The local hf field $H_{\text{loc}}$ is primarily induced by localized spins on the impurity through the core s electron polarization and is proportional to the impurity moment. The obtained values of $H_{\text{loc}}$ suggest a finite magnetic moment on the Mn impurity, which is estimated to be about $3 \mu_B$ in comparison with the value of Mn moment in Gd host [4], and nearly zero moments on Co and Ni. The positive sign of $H_{\text{loc}}$ for Mn indicates that the Mn local moment is antiferromagnetically coupled to the host Gd moments in many rare earth metallics [4, 5].

In conclusion, the systematics of the hf fields at 3d impurities in GdZn and GdCd is very similar to that in Gd metal. The large positive hf field at Mn suggests a local moment of about $3 \mu_B$ on the Mn impurity, which is antiferromagnetically coupled to the Gd moments in the hosts. The negative hf fields at Sc, Co, Ni and Cu can be explained by the conduction electron polarization transferred by neighbouring Gd moments, suggesting nearly zero moments on these impurities.

As for no observation of the $^{51}$V and $^{57}$Fe NMR, the similarity between the systematics of hf fields in GdZn(Cd) and Gd metal suggests that the $^{51}$V NMR is behind the intense $^{157}$Gd NMR line at 67 MHz and the $^{57}$Fe NMR occurs at a very low frequency. The examination of these points is now in progress by observing the $^{51}$VNMR in TbZn and the $^{57}$Fe Mössbauer effect in GdZn.

<table>
<thead>
<tr>
<th>nucleus</th>
<th>$H_{\text{ce}}$ (kOe)</th>
<th>$H_{\text{loc}}$ (kOe)</th>
<th>$H_{\text{loc}}$ (kOe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{55}$Mn</td>
<td>$-78.5$</td>
<td>$+166.5$</td>
<td>$+235.0$</td>
</tr>
<tr>
<td>$^{59}$Co</td>
<td>$-104.6$</td>
<td>$-108.6$</td>
<td>$-4.0$</td>
</tr>
<tr>
<td>$^{61}$Ni</td>
<td>$-118.1$</td>
<td>$-122.6$</td>
<td>$-6.5$</td>
</tr>
</tbody>
</table>

Table II. - The estimated values of the conduction electron field $H_{\text{ce}}$ and the local hf field due to impurity moment $H_{\text{loc}}$ at $^{55}$Mn, $^{59}$Co and $^{61}$Ni and GdZn and GdCd.