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Magnetic properties and phase transitions of $\text{RA}_x \text{Ga}_{2-x}$ ($R = \text{Tb, Ho}$)

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Abstract. — Crystal structure and magnetic properties of $\text{RA}_x \text{Ga}_{2-x}$ ($R = \text{Tb, Ho} : 0 \leq x \leq 2.0$) were investigated by means of X-ray and neutron diffraction, microprobe analysis and measurements of magnetic susceptibility.

Introduction. — $\text{RA}_2$ crystallize with cubic structures of $\text{MgCu}_2$ type (Laves phase) and order predominantly ferromagnetic [1]. On the other hand the antiferromagnetic $\text{RGa}_2$ occur with hexagonal $\text{AlB}_2$ type structure. Many other compounds of Al and Ga are isostructural [2]. Magnetic structures of $\text{RGa}_2$ were investigated at Grenoble [3]. We determined [4] the influence of Ga substitution by Al in $\text{RGa}_2$ on crystal structures and magnetic properties. One anticipates enhanced exchange associated with modified interatomic distances and band structures. Similar investigations concerning $\text{RAiGa}$ ($R = \text{Tb, Ho}$) were published recently by Gignoux and Asmat [5]. In contrast to this study our results furnish clear evidence for magnetic phase transitions in $\text{RAiGa}$ and substantially increased Néel temperature of $\text{TbAlGa}$ compared with $\text{TbGa}_2$. Coexistence of two helical phases is found in $\text{TbAl}_{1.05} \text{Ga}_{1.5}$.

1. Sample preparation, metallographic and X-ray investigations. — The samples were synthesized in an arc furnace in purest argon atmosphere from 99.999 % gallium (Alusuisse), 99.99 % aluminium (Alusuisse), 99.9 % holmium (Johnson, Matthey and Co., Ltd.) and 99.9 % terbium (Johnson, Matthey and Co., Ltd.) and remelted several times. The ingots were enclosed under vacuum in tantalum containers, homogenised at 1 000 °C for 24 h and finally annealed at 600 °C for 72 h. The samples were examined metallographically, by microprobe analysis and X-ray diffraction. The specimens prove to be homogeneous and correspond well to the nominal compositions.

Two phases exist in the composition range $\text{RA}_x \text{Ga}_{2-x}$. The $\text{AlB}_2$ phase exists over a range of $x = 0.0$ to 1.6, the $\text{MgCu}_2$ phase from $x = 1.25$ to 2.0, i.e. both phases coexist in the range $x = 1.25$ to 1.6. Concerning substitution of Ga by Al the cell constants of the $\text{AlB}_2$ phase show a remarkably nonlinear dependence, whereas the change of the $\text{MgCu}_2$ cell constants is small and linear (cf. figure 1).

![Fig. 1. — Cell constants (Å) versus Ga-content in $\text{HoAl}_x \text{Ga}_{2-x}$ series.](https://dx.doi.org/10.1051/jphyscol:1979560)
2. Magnetic susceptibility. — Figure 2 shows an example of the susceptibility measurements of TbAlGa, where (similar to HoAlGa) two transitions can be recognised.

Fig. 2. — Susceptibility measurements of TbAlGa compound (emu).

3. Neutron diffraction studies. — Powder samples of RA15Ga2-x (cf. table 1) were investigated by neutron diffraction at Würrenlingen. Illustrative, absorption corrected patterns (wavelength 2.35 Å) are shown in figure 3. The nuclear intensities confirm the AlB2-structure model with statistical distribution of Al and Ga on B sites. RA15Ga2-x (R = Tb, Ho; x < 1) order antiferromagnetically (cf. figure 3 and table 1). At x = 1 Néel temperatures are considerably larger compared to x = 0. The low temperature magnetic structure of HoAlGa (cf. figure 4) corresponds to Shubnikov group P6/mcc and is similar to CsCoCl3 [6]. The incommensurate configurations are spiral structures of triangular type within (001) planes [phase angles ± (120°, 240°)], with propagation direction c (K = [1/3, 1/3, q]) and q increasing systematically with composition x.

Table I. — Neutron results for RA15Ga2-x. \(T_N\) = Néel temperature, \(T_i\) = temperature of magnetic phase transition, MS = magnetic structure. A denotes triangular moment configuration with undetermined orientation within (001) planes. \(\mu\) = ordered magnetic moment. Standard deviations within parentheses refer to the last digit. * more stable above 15 K.

<table>
<thead>
<tr>
<th>R</th>
<th>x</th>
<th>Tb</th>
<th>0.5</th>
<th>1.0</th>
<th>Ho</th>
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<tbody>
<tr>
<td></td>
<td>(T_N) [K]</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ho</td>
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<td>17.8 [2]</td>
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<tr>
<td></td>
<td>(q)</td>
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<tr>
<td></td>
<td>(\mu_r)</td>
<td>0.419*</td>
<td>0.483 [&gt; (T_i)]</td>
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<tr>
<td></td>
<td>MS</td>
<td>(\Delta)</td>
<td>(\Delta) [&gt; (T_i)]</td>
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<tr>
<td></td>
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<td>+ --- [&lt; (T_i)]</td>
<td>+ --- [&lt; (T_i)]</td>
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</tr>
</tbody>
</table>

Table I.

Fig. 4. — Low temperature magnetic structure of RA15Ga (R = Tb, Ho) [moments reversed at \(z = 1/2\)]. Signs indicate \(z\) components.

Fig. 3. — Neutron diffraction patterns of HoAlGa. At 4.2 K magnetic reflections are indexed with respect to the magnetic \((a_m = 3 a, c_m = 2 c)\) unit cell. \(\theta_2 = \pm q\).
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References