# Multiple magnetic transitions in $Gd_5Rh_4Ge_{10}$ single crystal

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**Abstract**

We report the observation of quadruple magnetic transitions in a single crystal of $Gd_5Rh_4Ge_{10}$ at 14.0 K, 12.0 K, 8.5 K and 7 K via resistivity, susceptibility and heat capacity studies. At least two of these transitions at 8.5 K and 7 K are completely suppressed in a field of 5 T applied along the c-axis while they are marginally suppressed for the same field along the a-axis. Multiple ordering in Gd based compounds is rare occurrence due to the S state nature of Gd ion and we provide a plausible scenario to explain these transitions.

*Key words:* Antiferromagnetic transitions; $Gd_5Rh_4Ge_{10}$; single crystal;

Rare-earth compounds with the tetragonal $Sc_5Co_4Si_{10}$ (P4/mbm) prototype structure show the coexistence of magnetism or superconductivity with charge-density-wave ordering at higher temperatures [1]. In particular, $Gd_5Rh_4Ge_{10}$ shows multiple magnetic ordering below 14 K [2]. Usually one observes at best only two magnetic transitions in Gd-based intermetallic compounds [3]. Hence, the observation of four transitions in a single crystal of $Gd_5Rh_4Ge_{10}$ is a unique feature and to the best of our knowledge has not been reported in any Gd-based intermetallic compounds. From what we see in the experimental data (described below), the sharper fall in the heat capacity ($C_p$) at 14 K on the high-temperature side probably implies a usual second-order transition whereas the other three transitions, which occur at low temperatures, could be due to successive spin-reorientation effects. The magnetic susceptibility ($d\chi/dT$ data) and resistivity data are in agreement with the above-mentioned scenario. The temperature dependence of the susceptibility ($\chi$) data along a and c-axes are shown in the Fig. 1. We note that the anisotropy in $\chi$ builds up below 50 K due to magnetic

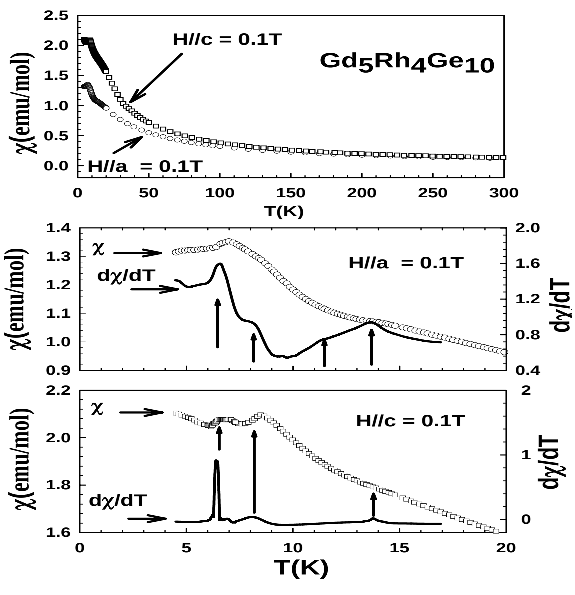


Fig. 1. The temperature dependence of magnetic susceptibility ($\chi$)and $d\chi/dT$. The arrows indicate multiple transitions.

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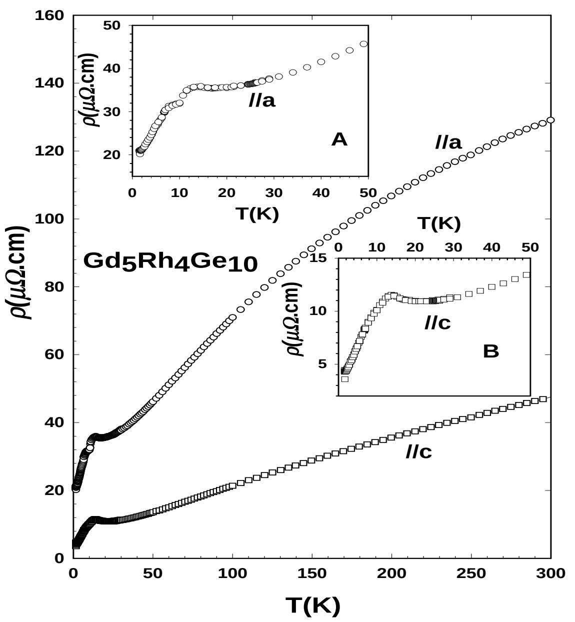


Fig. 2. The temperature dependence of the resistivity along a and c-axes. The inset panels show the low temperature data. Slope change in $\rho$ occurs at 14 K and 12 K (panel A).

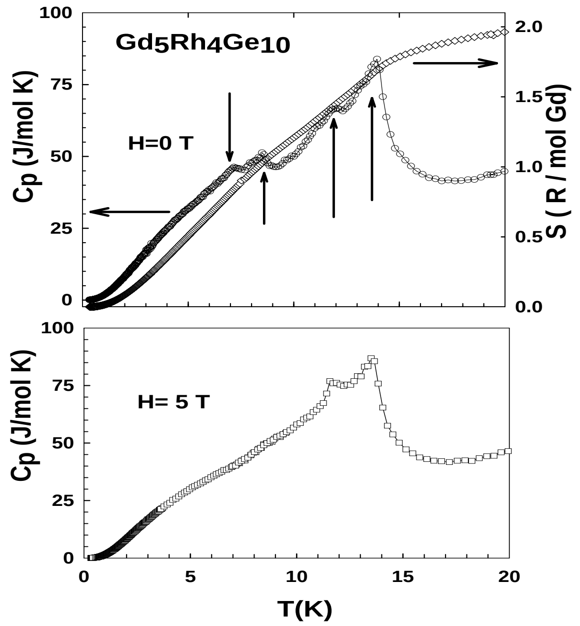


Fig. 3. The temperature dependence of heat capacity at H=0 and H=5 T. The top panel also shows the temperature dependence of the estimated entropy(S) value. The arrows mark the quadruple transitions at 14, 12, 8.5 and 7 K at H=0 in the top panel.

fluctuation effects and ultimately the $\chi_c$ is $1.5\times\chi_a$ at 2 K. The lower panels display the low temperature $\chi$ data along both axes with their derivatives. From this plot we can clearly distinguish quadruple magnetic transitions at 7 K, 8.5 K, 12 K and 14 K along the a-axis. However, only three such transitions (7, 8.5 and 14 K) are discernable along c-axis. The high temperature data (100 K<T<300 K) could be fitted to the Curie-Weiss expression from which we estimated $\mu_{eff}$=8.0 $\mu_B$ and $\theta_p$=6 K.

The temperature dependence of the resistivity ($\rho$) data along a and c-axes are shown in the Fig. 2. The anisotropy in the resistivity is about 3 at 300 K but increases to 5 at 2 K suggesting considerable contribution to the magnetic scattering along the a-axis. As in the case of $\chi$ data, the d$\rho$/dT (not shown here) behavior suggests four magnetic transitions. The temperature dependence of $\rho$ at low temperature does not show a $T^2$ dependence implying a complex magnetic ordering in this compound. Moreover, a jump in the resistivity at 12 K (see the upper inset panel) implies a first order magnetic transition.

The heat capacity data from 2 to 20 K at H=0 and H=5 T along the c-axis are shown in Fig. 2. The quadruple transitions at 7 K, 8.5 K, 12 K and 14 K can be distinguished from this figure. The low temperature transitions are almost suppressed at H= 5 T. The estimated entropy per Gd ion displayed in the top panel is 1.97 R which is almost equal to the total entropy for $Gd^{3+}$ ion [Rln(2J+1)]. However, it is evident that the full entropy is not released at 14.0 K, which implies the existence of short-range correlations above $T_N$. Moreover, the jump in the heat capacity at 14 K is only 8 J/mol Gd K which is much smaller than the expected mean field value of 20.15 J/mol K. Normally such a mean field value for the heat capacity jump is expected for a ferro or simple antiferromagnet [3] (equal moment systems). Since the observed $C_p$ jump in $Gd_5Rh_4Ge_{10}$ is small there is a possibility that the magnetic moment amplitude may vary periodically from one site to another, evolving from a sine-wave shape just below $T_N$ to an antiphase-type at low temperatures. Such amplitude modulated moments possibly undergo multiple reorientation as we have observed here. Microscopic measurements such as, magnetic dichroism and electron spin resonance are needed to understand these unusual magnetic transitions.

## References


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