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# Resistivity and magnetoresistance studies on $RCoGe_3$ (R = La, Ce) compounds

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**Abstract.** Resistivity ($\rho$) and magnetoresistance ($\Delta\rho/\rho(0)$) have been measured for polycrystalline $LaCoGe_3$ and $CeCoGe_3$ compounds. The temperature dependence of $\rho$ for the La compound is described by $\rho \propto T^3$ for $T \ll \vartheta_D$ and $\propto T$ at high temperatures. At 4.5 K a significantly large $\Delta\rho/\rho(0)(\sim 1)$ is observed. In $CeCoGe_3$ $\rho(T)$ exhibits a sharp drop below the magnetic ordering temperature, 21 K. In the antiferromagnetic region between 4 and 16 K it follows a quadratic temperature dependence. The magnetic contribution to resistivity, $\rho_m$, exhibits a maximum at ~125 K above which it decreases following a logarithmic temperature dependence. The magnetoresistance remains positive for temperatures between 4.5 and 30 K but shows field induced transitions at ~7 kOe and ~28 kOe.

## 1. Introduction

Tetragonal systems with $ThCr_2Si_2$ structure have been a subject of extensive investigation [1]. Compounds with similar structure but of lower symmetry, i.e. $BaNiSn_3$-type structure also are found to exhibit a wide variety of behaviour but are less studied. $CeFeGe_3$ is a non-magnetic compound with high Kondo temperature [2]. $CeNiGe_3$ exhibits magnetic ordering below 4.2 K [3]. $CeCoSi_3$ is a superconductor with $T_C \sim 1.4$ K [4]. $CeCoGe_3$ is reported be a heavy fermion system and also exhibits complex temperature and field induced magnetic behaviour below 21 K [5]. To shed more light on the various magnetic phases we have carried out resistivity and magnetoresistance measurements on $LaCoGe_3$ and $CeCoGe_3$, the results of which are reported here.

## 2. Experimental details

The samples were prepared by arc melting the stoichiometric amounts of the constituent elements in Ti-gettered argon atmosphere. The buttons were then chill cast drawn in the form of rods for transport measurements. These were sealed in an evacuated quartz tube and annealed at 800 °C for one week. X-ray powder diffraction measurements reveal them to be single phase with a $BaNiSn_3$-type structure (space group *I*4*mm*). The tetragonal cell parameters calculated using a least squares fit method are $a = 4.346$ Å and $c = 9.870$ Å

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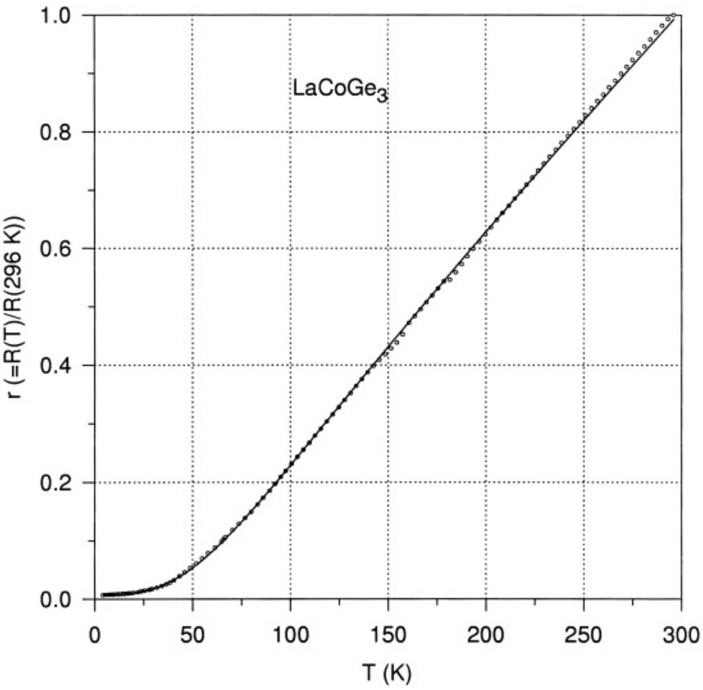


**Figure 1.** The temperature dependence of normalized resistance, $r(= R(T)/R(296\text{ K}))$ of $LaCoGe_3$. The continuous line is the fit to the equation discussed in the text.

for $LaCoGe_3$ and $a = 4.314$ Å and $c = 9.815$ Å for $CeCoGe_3$, in agreement with reported values [5]. Dc resistivity and magnetoresistance measurements were measured using a standard four-probe method.

## 3. Results and discussion

### *3.1. $LaCoGe_3$*

The value of $\rho(296\text{ K})$ is 57 $\mu\Omega$ cm and the residual resistivity ratio (RRR), $R(296\text{ K})/R(4.2\text{ K})$ is found to be 150. The variation of normalized resistance, $r(= R(T)/R(296\text{ K}))$ as a function of temperature is shown in figure 1. The temperature dependence of $r$ exhibits a normal metallic behaviour as the temperature is reduced. It does not exhibit either magnetic or superconducting transition down to 4.2 K. The value of $\rho(296\text{ K})$ is nearly half the reported value of $\sim$100 $\mu\Omega$ cm in $LaCoSi_3$ with similar structure [4]. This large value of RRR for a polycrystalline sample suggests a very ordered system. The temperature dependence of the resistivity could not be fitted to a Bloch–Grüneisen relation where for $T \ll \theta_D$, $\rho \propto T^5$. Instead in the region between 4.2 and 300 K the temperature dependence of the resistivity could be fitted to an expression of the form

$$\rho(T) = \rho(0) + c_1 \left(\frac{T}{\theta_D}\right)^3 \int_0^{\theta_D/T} \frac{x^3\,\mathrm{d}x}{(1 - \mathrm{e}^{-x})(\mathrm{e}^x - 1)}$$

where $\rho(0)$ is the residual resistivity, the second term is due to the electron–phonon scattering and $\theta_D$ is the Debye temperature. The continuous line through the data points in figure 1 indicate the fitted line. The fit holds good except for the region $T > 250$ K where differences

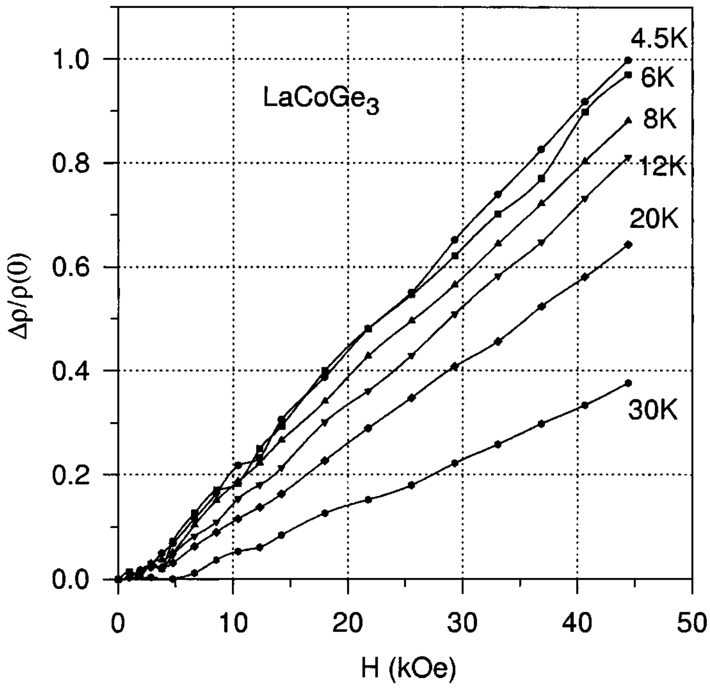


**Figure 2.** The magnetic field dependence of the magnetoresistance of LaCoGe$_3$ at various temperatures.

appear between the fitted and observed values. For $T \ll \theta_D$, $\rho \propto T^3$. This form of temperature dependence has also been observed in the case of $La_2Rh_3Si_5$ [6] and attributed to Wilson's s–d scattering model. $\theta_D$ has been used as a parameter. The value of $\theta_D (= 360$ K) obtained from the fit is in good agreement with that obtained from independent specific heat measurements [5]. Its value is larger than that reported (=298 K) in the case of LaFeGe$_3$ [2].

The magnetoresistance MR, $\Delta\rho/\rho(0)(= [\rho(H) - \rho(0)]/\rho(0))$ as a function of magnetic field at various temperatures is shown in figure 2. It is positive at all temperatures between 4.2 and 30 K and its magnitude at a given field decreases with increase in temperature. It varies nearly linearly with field at all temperatures. The magnitude of MR at 4.2 K and 45 kOe is almost 1.0. This denotes a significantly large value for a polycrystalline sample. In comparison for LaCu$_6$ $\Delta\rho/\rho(0)$ is only $\sim$0.11 at a similar temperature and field [7]. The large value for $\Delta\rho/\rho(0)$ could possibly be due to the low value of $\rho$(4.2 K). It is found that the temperature dependence of MR is in agreement with the Kohler law i.e. $\Delta\rho/\rho(0) = f(H/\rho(0))$. In figure 3 we show the plot of $\Delta\rho/\rho(0)$ against $H/\rho(0)$. It is observed that all the data points between 4.2 and 30 K fall on a single curve. The validity of Kohler's plot over a wide temperature range indicates the absence of spin dependent scattering.

### *3.2. CeCoGe$_3$*

The resistivity $\rho$, of CeCoGe$_3$ at 300 K is 127 $\mu\Omega$ cm and RRR $\sim$30. The temperature variation of resistivity is shown in figure 4. The resistivity decreases as the temperature is lowered. However, the variation in $\rho$ between 300 and 150 K is only $\sim$15 $\mu\Omega$ cm as compared to a large decrease of $\sim$100 $\mu\Omega$ cm below 100 K. There is a marked change in the behaviour of $\rho$ at $\sim$21 K

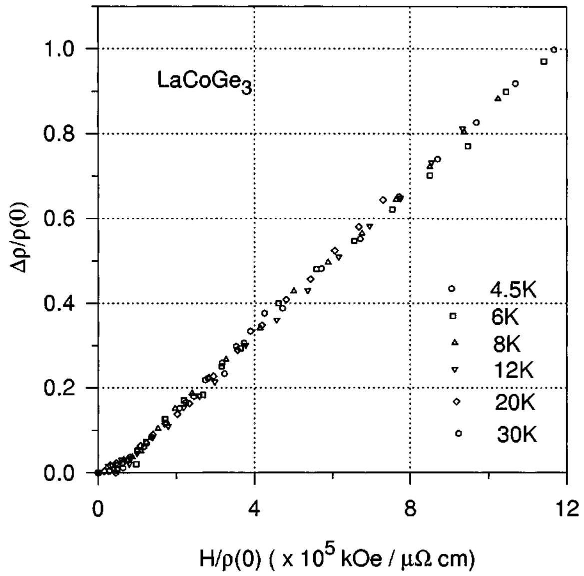


**Figure 3.** The magnetoresistance as a function of $H/\rho(0)$ of $LaCoGe_3$ at various temperatures.

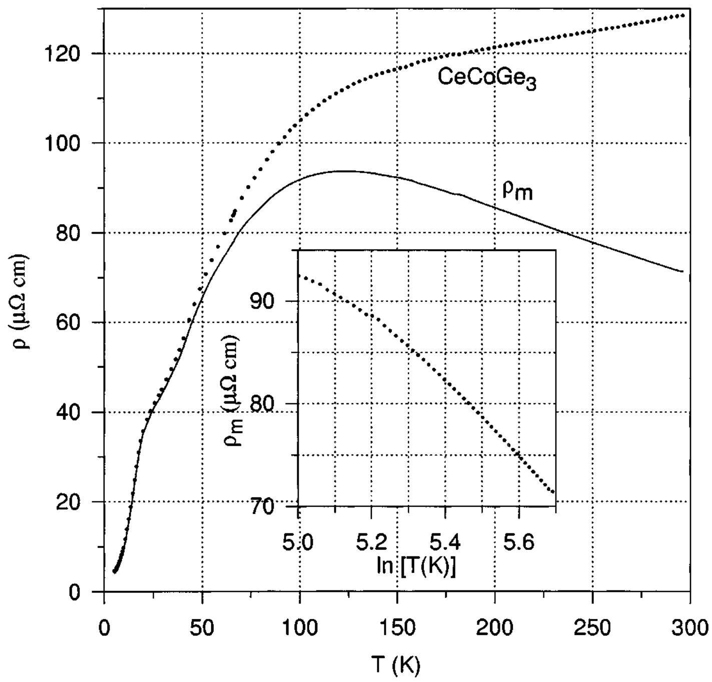


**Figure 4.** The temperature dependence of resistivity of $CeCoGe_3$ and $\rho_m$ ($=\rho(CeCoGe_3)$ $-\rho(LaCoGe_3)$). The inset shows the logarithmic temperature variation of $\rho_m$.

indicating the transition to a magnetically ordered state below this temperature. The behaviour of $d\rho/dT$ (figure 5) gives a better picture. It exhibits a maximum at 16.5 K and is identified with the antiferromagnetic transition. This is in agreement with the reported magnetic phase diagram

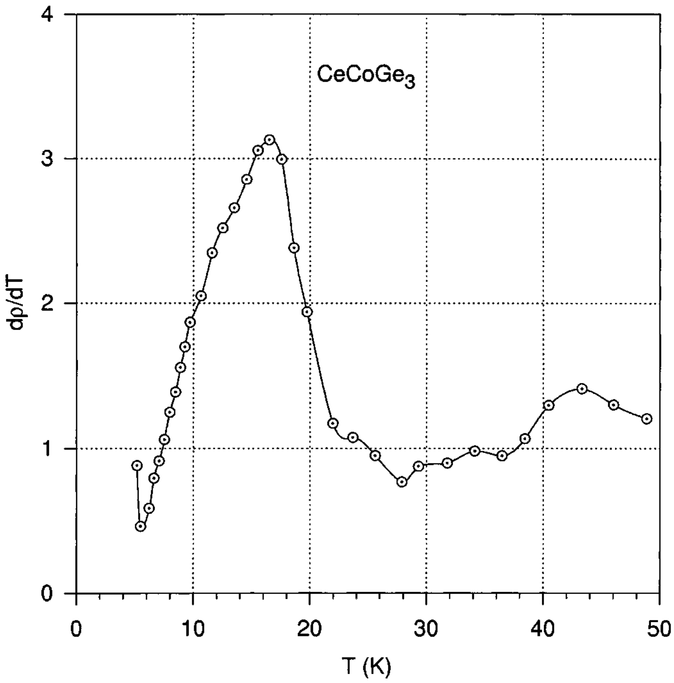


**Figure 5.** The temperature variation of $\mathrm{d}\rho/\mathrm{d}T$ of $CeCoGe_3$.

[5], where it is proposed that the system in zero magnetic field undergoes a paramagnetic to a ferrimagnetic transition at 21 K and subsequently to an antiferromagnetic phase below 16 K. However, from the derivative plot the para to ferrimagnetic transition is not very clear: $\mathrm{d}\rho/\mathrm{d}T$ continuously increases below 22 K. It needs to be pointed out that no negative $\mathrm{d}\rho/\mathrm{d}T$ in the temperature region around the ordering temperature, 16.5 K is observed. Normally the onset of commensurate antiferromagnetic order is associated with an increase in $\rho$ due to the magnetic superzone gap effect [8, 9], which results in negative $\mathrm{d}\rho/\mathrm{d}T$ at the $T_N$. Its absence here could be a result of either the formation of intervening ferrimagnetic state between para and AF or the absence of the gap itself. Below $T_N$, $\mathrm{d}\rho/\mathrm{d}T$ steadily decreases due to the increase in AF order. Between 4.5 and 16 K $\rho(T)$ exhibits a quadratic temperature dependence of the form $\rho(T) = \rho(0) + AT^2$ where $\rho(0) = 1\ \mu\Omega$ cm and $A = 0.096\ \mu\Omega$ cm $\mathrm{K}^{-2}$. The value of $A$ is of the same magnitude as reported in the case of $\alpha$-Mn, $A = 0.11\ \mu\Omega$ cm $\mathrm{K}^{-2}$ [10]. The larger value of $\rho(0)$ as compared to $LaCoGe_3$ is attributed to the contribution from antiferromagnetic coupling of magnetic moments. For $T > 21$ K the difference in the variation of $\rho$ between the normal metallic behaviour in $LaCoGe_3$ and $CeCoGe_3$ is attributed to the magnetic contribution to $\rho$ in $CeCoGe_3$. Assuming that the phonon contribution is similar in both the compounds we estimate the magnetic contribution to $\rho$ in $CeCoGe_3$, $\rho_m(= \rho(CeCoGe_3) - \rho(LaCoGe_3))$. $\rho_m$ exhibits a broad maximum at ~125 K above which it decreases. It follows a $-\ln T$ behaviour for $T > 170$ K (shown in the inset of figure 4). The earlier report of resistivity studies on this compound shows a linear variation of $R(T)$ for 21 K $< T <$ 100 K [5]. Our results clearly show the highly non-linear behaviour of $\rho$ above the magnetic ordering temperature. The maximum in $\rho_m$ at 125 K is understood to be a result of the Kondo effect influenced by crystal field effects as discussed by Cornut and Coqblin [11]. The temperature at which $\rho_m$ is a maximum is an indication of the energy difference between the crystal field split energy

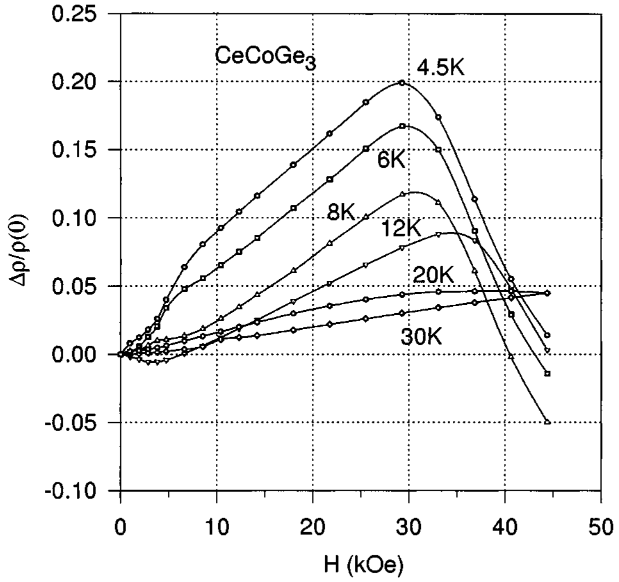


**Figure 6.** The magnetic field variation of magnetoresistance of $CeCoGe_3$ at various temperatures.

levels. Our observations indicate that the lowest excited crystal field level is ∼100 K and the value is of the same order as deduced from zero-field heat capacity results [5]. It is of interest to note that the high temperature resistivity behaviours are similar in the case of $CeFeGe_3$ [2], $CeNiGe_3$ [3] and the present compound, irrespective of the ground state. The maximum in $\rho_m$ occurs at ∼100 K suggesting similar CEF splitting in these compounds.

The variation of $\Delta\rho/\rho(0)$ with magnetic field at various temperatures is shown in figure 6. It is positive for all temperatures between 4.2 and 30 K but shows two field induced transitions. The first transition at $H \sim 7$ kOe results in increase in resistance whereas the second transition at $H \sim 28$ kOe is accompanied by a significant decrease in resistance (∼0.20). Knowing the magnetic phase diagram [5] the various transitions are identified with three distinct regions. For $H<7$ kOe in the antiferromagnetic state $\Delta\rho/\rho(0)$ varies as $H^n$ with $n>1$. As temperature is increased this transition disappears rapidly. Between 10 and 28 kOe the variation is nearly linear in the state where the magnetic state is a mixture of AF and ferrimagnetic. For $H > 29$ kOe the slope of $\Delta\rho/\rho(0)$ changes from positive to negative indicating the transition to a ferromagnetic state. The field, $H_m$ at which the maximum in $\Delta\rho/\rho(0)$ occurs shifts to higher fields as the temperature is increased from 4.2 to 12 K. The observed behaviour of the shift of $H_m$ to higher field as temperature is increased is similar to that reported from the magnetization measurements [5]. This is different from similar metamagnetic behaviour observed in $CeRh_2Ge_2$ where the field $H_m$ is found to shift to lower fields as the transition temperature is approached [12].

## 4. Conclusions

The temperature dependence of resistivity for $LaCoGe_3$ is described by $\rho \propto T^3$ for $T \ll \vartheta_D$ and $\propto T$ at high temperatures. The magnetoresistance $\Delta\rho/\rho(0)$ at 4.5 K exhibits larger values than at higher temperatures and follows Kohler's law indicating the absence of spin dependent scattering. For $CeCoGe_3$, $\rho(T)$ exhibits a magnetic ordering below 21 K. Below the ordering temperature a quadratic temperature dependence is followed. The magnetic contribution to resistivity, $\rho_m$ exhibits a maximum at $\sim$125 K above which it follows a $-\ln T$ behaviour indicating the influence of crystal fields on the Kondo effect. The variation of $\Delta\rho/\rho(0)$ as a function of $H$ indicates transitions at 7 and 28 kOe.

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