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LETTER TO THE EDITOR

Large magnetoresistance anomalies in Dy₇Rh₃**Kausik Sengupta, S Rayaprol and E V Sampathkumaran**

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Abstract

The compound Dy₇Rh₃ ordering antiferromagnetically below ($T_N=$) 59 K has been known to exhibit a temperature (T) dependent electrical resistivity (ρ) behaviour in the paramagnetic state unusual for intermetallic compounds in the sense that there is a broad peak in $\rho(T)$ in the paramagnetic state (around 130 K) as though there is a semiconductor to metal transition. In addition, there is an upturn below T_N due to magnetic super-zone gap effects. Here we report the influence of external magnetic field (H) on the $\rho(T)$ behaviour of this compound below 300 K. The rise of $\rho(T)$ found below T_N could be suppressed at very high fields ($\gg 60$ kOe), thus resulting in a very large magnetoresistance (MR) in the magnetically ordered state. The most notable finding is that the magnitude of the MR is large for moderate applications of H (say 80 kOe) in a temperature range far above T_N as well, which is untypical of intermetallic compounds. Thus, this compound is characterized by large MR anomalies in the entire T range of investigation.

During the last decade, there have been considerable efforts in identifying materials exhibiting large magnetoresistance (MR), particularly near room temperature, considering its application potential. Such reports are however scarce among intermetallics due to the fact that the net magnitude of MR caused by the influence of external field (H) on the cyclotron motion of the conduction electrons as well as on the paramagnetic moments is usually negligible in the vicinity of room temperature. In this letter, we report the influence of H on the temperature (T) dependent electrical resistivity (ρ) behaviour of an intermetallic compound, Dy₇Rh₃, which is found to exhibit interesting magnetoresistive response in the entire temperature of investigation. It may be remarked that the compounds of the type R₇Rh₃ (R = rare-earths), crystallizing in the Th₇Fe₃-type hexagonal structure ($P6_3mc$), are of an unusual type among the rare-earth intermetallics in the sense that the light R members behave like metals, whereas in heavier members there are temperature regions in which the T -coefficient of ρ is negative not only in the magnetically ordered state but also in the paramagnetic state [1–3]. Such features are believed to arise from the existence of a band gap, which is sensitive to lanthanide contraction effects in this series.

A polycrystalline sample of Dy₇Rh₃ was synthesized by arc-melting high purity constituent elements in argon atmosphere. The molten ingot was annealed at 600 °C for

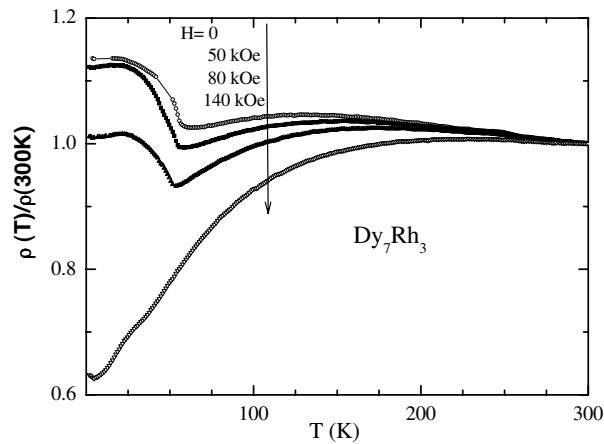


Figure 1. Electrical resistivity of Dy_7Rh_3 as a function of temperature measured in the presence of magnetic fields, normalized to respective 300 K values.

2 days in vacuum and characterized by x-ray diffraction. The powder x-ray diffraction pattern established that the sample was single phase, and the lattice parameters are in close agreement with the reported ones [3]. The dc ρ measurements were performed in the T interval 1.5–300 K by a four-probe method in the presence of various H employing the physical property measurements system (Quantum Design). In addition, the measurements were performed as a function of H at selected temperatures.

In figure 1, the temperature dependence of $\rho(T)/\rho(300\text{ K})$ is plotted. The value of ρ at 300 K is typically of the order of $300\ \mu\Omega\text{ cm}$. It is obvious that, for $H = 0$, the sign of $d\rho/dT$ is clearly negative above 150 K due to a semimetallic band gap of about 9 meV [3]; around 130 K there is a broad peak followed by a gradual fall as T is further lowered in the paramagnetic state as though there is a semimetallic–metallic continuous transition. There is a sudden upturn in ρ near 50 K after the onset of antiferromagnetic ordering due to the formation of a magnetic super-zone gap. While these findings are in broad agreement with those reported in the literature on polycrystals [3], a drop seen below 34 K in [3] is absent in our samples, in agreement with the features exhibited by the single crystalline form [4]. We find that the features are qualitatively unaffected by the application of H in the paramagnetic state, though the maximum appears to shift to a higher T range with increasing field, say to 200 K at 140 kOe. These results imply that the paramagnetic transport behaviour is robust to the application of H . As the sample enters the magnetically ordered state, the $\rho(T)$ behaviour qualitatively remains unaffected until $H = 80$ kOe, while for $H = 140$ kOe, the upturn vanishes as though the magnetic gap can be suppressed by such large fields only.

We now look at the trends observed in the absolute values of ρ as H is varied. For this purpose, we have derived the magnitudes of the MR ($=[\rho(H) - \rho(0)]/\rho(0)$) as a function of T . The results are shown in figure 2. Clearly, for $H = 50$ and 80 kOe, the magnitude of the MR increases with decreasing T , attaining a peak near the magnetic transition (as large as -13% for $H = 80$ kOe), while the magnitude keeps growing down to very low temperatures for $H = 140$ kOe, attaining a value of about -45% at 1.8 K. The magnitude remains large (-28%) even at temperatures as high as 50 K for 140 kOe. The large MR with a negative sign in the high-field range originates from the reconstruction of the Fermi surface due to the collapse of the magnetic super-zone gap resulting in a recovery of the carrier concentration.

In order to have a closer look at the magnitudes of the MR, we show in figure 3 the values of the MR at several temperatures, obtained by measuring ρ as a function of H .

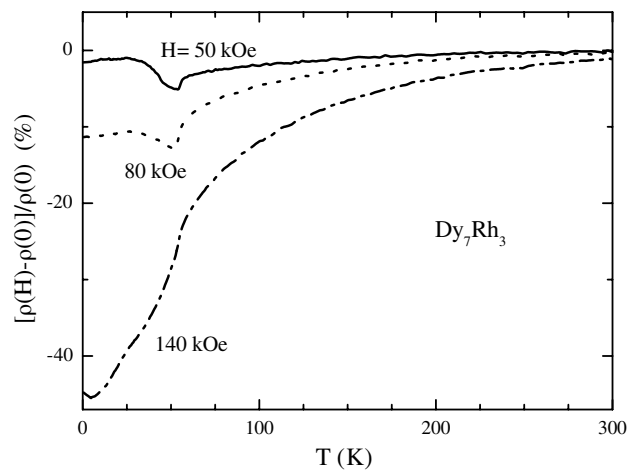


Figure 2. The magnetoresistance as a function of temperature for Dy_7Rh_3 derived by taking the resistance data at fixed H values.

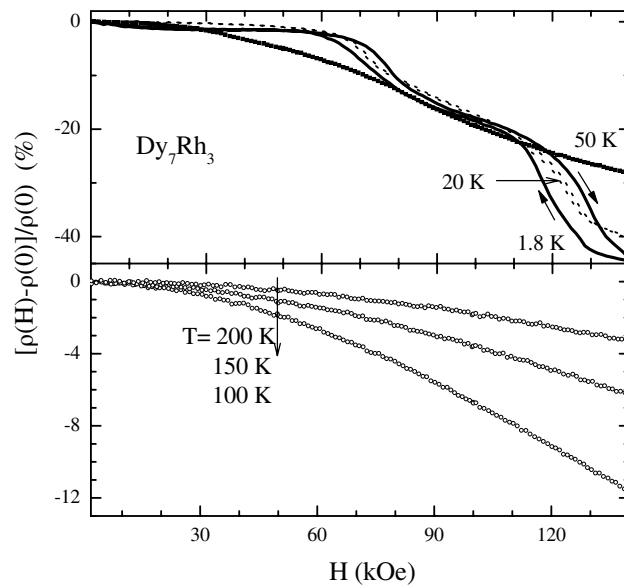


Figure 3. Magnetoresistance of Dy_7Rh_3 as a function of magnetic field measured at selected temperatures.

In the magnetically ordered state, though the response of ρ to initial applications of H is rather negligible, it is clear that the magnitude becomes large at higher fields as noted above. Another finding we make is that there are steeper changes in the MR near 60 and 120 kOe for $T = 1.8$ and 20 K, and these are found to be hysteretic. We attribute these to the existence of metamagnetic transitions (first-order-like, but presumably broadened by defects), inferred from the isothermal magnetization studies on single crystals in [4]. But such a transition is absent at 50 K, as evidenced by the present data seen in figure 3; the shape of the MR plot at 50 K is in fact different from those observed at lower temperatures, which implies that the magnetic structure varies as T is lowered from 50 to 20 K.

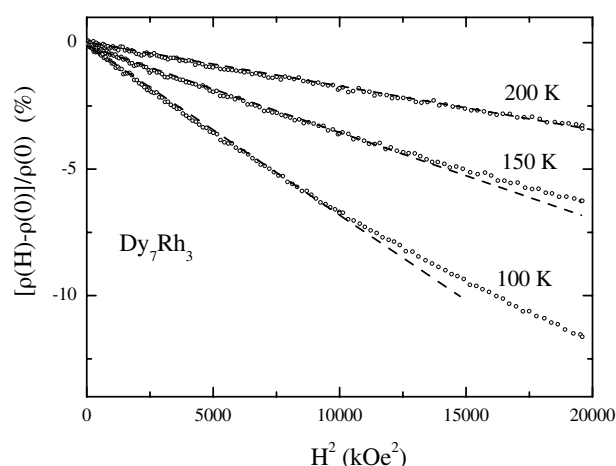


Figure 4. A plot of magnetoresistance versus the square of the magnetic field for Dy_7Rh_3 at various temperatures in the paramagnetic state. Dashed lines are drawn through the quadratic region.

We now focus on the MR behaviour in the paramagnetic state (see, for instance, figure 3, bottom). We find that the sign of the MR is negative and that the MR varies essentially quadratically (see figure 4) for moderate applications of H , typical of the influence of H on the paramagnetic moments; for large enough field values, there is a deviation from quadratic behaviour possibly due to an influence of H on the Fermi surface (on the band gap). The most interesting point is that the observed magnitudes of the MR in the high field region are reasonably large. Thus, even at temperatures as high as 200 and 150 K, the values are about -3% and -5.5% at 140 kOe. Possibly, the influence of H on the band gaps at the Fermi surface also plays a role in determining the large magnitude of the MR. We hope that this observation will motivate further investigations in this regard.

Summarizing, the intermetallic compound Dy_7Rh_3 exhibits interesting temperature dependent ρ behaviour, the qualitative features of which are quite robust to the presence of moderate magnetic fields (say, 80 kOe). However, the absolute values of the MR are quite large not only in the magnetically ordered state (below 50 K), but also in the paramagnetic state for H beyond certain values. The values observed in the range 100–200 K are comparable to those in a few other intermetallic compounds [5, 6], which have been classified as *metallic* giant magnetoresistance systems in this temperature range. While the MR anomaly arises in the paramagnetic state itself¹ in the present compound, for the latter compounds the anomalies are essentially in the magnetically ordered state, due to field-induced changes in the spin orientation. In that sense, the present compound presents a new situation.

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¹ Large MR in the paramagnetic state due to the suppression of anomalously large spin-disorder contribution by H has been reported earlier by us for lower temperature ranges. See, for instance [7].