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Antiferromagnetism in the $Dy_5Ir_4Si_{10}$ system

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In this paper we report the dc susceptibility and resistivity studies of the antiferromagnet $Dy_5Ir_4Si_{10}$. We find that this compound undergoes an antiferromagnetic transition at 5.0 K and the effective magnetic moment observed is $10.6\mu_B$, which is equal to the free-ion value for the Dy atom. However, the resistivity shows a broad minimum at 17 K and a maximum at 6.5 K before it decreases below 6 K. We attribute this behavior of the resistivity to magnetic superzone effects in this compound.

I. INTRODUCTION

Most of the studies on the coexistence of superconductivity and magnetism are made either on RMo_6S_8 chalcogenides or on the RRh_4B_4 borides (R is a rare-earth element).[1] In these systems the superconductivity arises due to Mo clusters and Rh clusters, respectively, while magnetism is due to the rare-earth element. In the case of ternary silicides $Dy_5Ir_4Si_{10}$ (Ref. 2) (where there are no clusters and no direct transition-metal–transition-metal contact), it is of interest to study the nature of the magnetism displayed by the rare-earth element. With this motivation, we have studied the previously reported (only T_N, the antiferromagnetic transition temperature) $Dy_5Ir_4Si_{10}$ compound. We not only confirm the antiferromagnetic (AF) transition but also determine an effective-magnetic-moment value of $10.6\mu_B$, which is equal to the free-ion value of Dy. Furthermore, we also found that the resistivity (ρ) shows a broad minimum at 17 K and rises up to 6.5 K before it decreases below 6 K, signifying magnetic superzone effects in this compound.

II. EXPERIMENTAL DETAILS

The sample $Dy_5Ir_4Si_{10}$ was made by melting the individual constituents in an arc furnace under high-purity argon atmosphere. The purity of Dy and Ir is 99.9% while that of Si is 99.999%. The sample was found to have the tetragonal structure of the type $PM3N$ ($Sc_5Co_4Si_{10}$ structure) and the lattice constants a and c agree with the previously published values.[2] The temperature dependence of susceptibility (χ) was measured using a Quantum Design SQUID magnetometer in a field of 1 kOe from 2 to 300 K. The resistivity was measured using a four-probe dc technique and the contacts were made using ultrasonic solder (with indium) on a cylindrical sample of 2 mm diameter and 10 mm length. The temperature was measured using a calibrated Si diode (LAKE SHORE) sensor. The sample voltage was measured with a Keithley nanovoltmeter with a current of 25 mA using a 20 ppm stable HP current source.

III. RESULTS AND DISCUSSION

A. Susceptibility studies

The temperature dependence of χ of $Dy_5Ir_4Si_{10}$ from 2 to 300 K is shown in Fig. 1. The temperature dependence of χ from 2 to 30 K is shown in the inset. One can observe the AF state around 5.0 K where $(d\chi/dT)$ shows a maximum. The high-temperature χ ($100\ \mathrm{K} < T < 300$ K) data are well fitted by the Curie-Weiss law $[\chi(T)=C/(T-\Theta_N)]$, which is shown in Fig. 2. The value of Θ_N from this fit is 16 K which is higher than the T_N value. Further, the effective magnetic moment calcu-

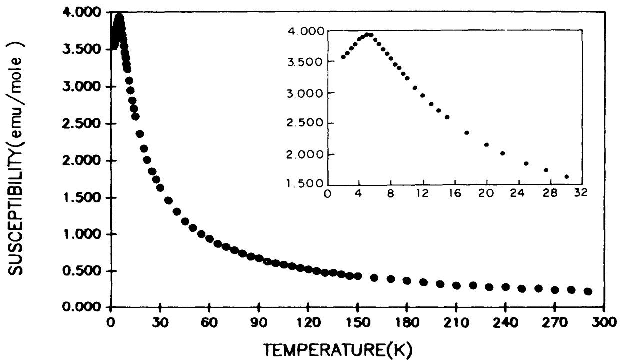

FIG. 1. Variation of susceptibility χ of $Dy_5Ir_4Si_{10}$ from 2 to 300 K. The inset shows χ from 2 to 30 K.

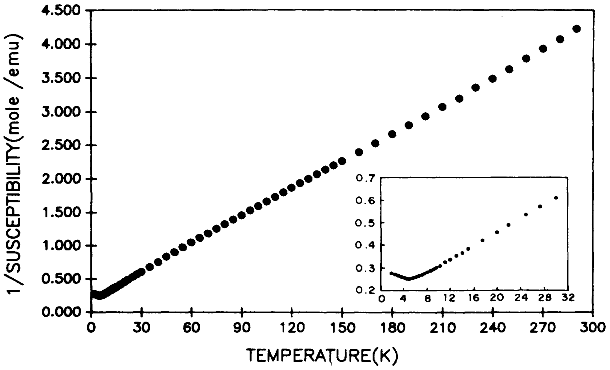

FIG. 2. Plot of $1/\chi$ with temperature from 2 to 300 K which shows the linear dependence. The inset shows the same dependence from 2 to 35 K.

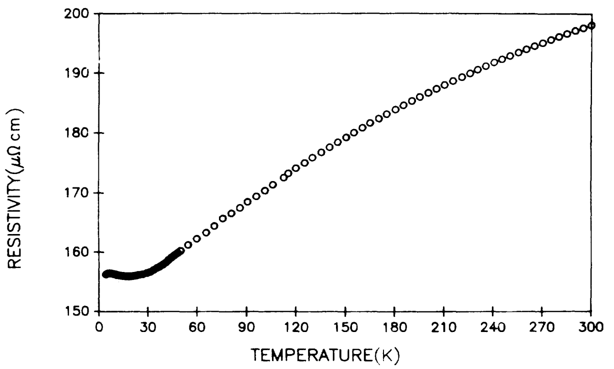

FIG. 3. Temperature dependence of $\rho(T)$ of $Dy_5Ir_4Si_{10}$ from 2 to 300 K.

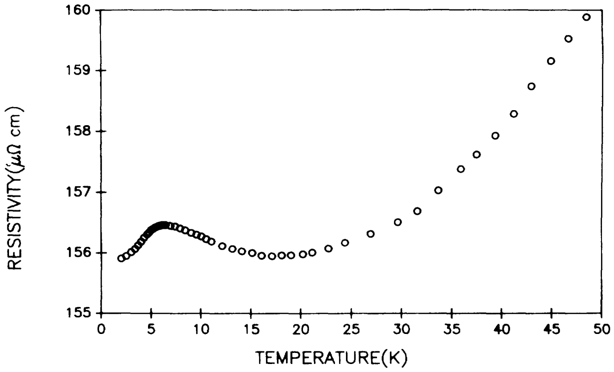

FIG. 4. Temperature dependence of $\rho(T)$ of $Dy_5Ir_4Si_{10}$ from 2 to 50 K.

lated ($\mu_{\text{eff}}=\sqrt{8C}$) from this data is $10.6\mu_B$, which agrees with the free-ion value of Dy, $10.63\mu_B$.

B. Resistivity studies

The temperature dependence of resistivity (ρ) from 2 to 300 K is shown in Fig. 3. The low temperature ρ (2 K $< T <$ 50 K) is shown in Fig. 4. Here we find a broad minimum in ρ at 17 K then it rises up to 6.5 K and decreases. Such a minimum has been seen in many antiferromagnetic rare-earth metals[3-5] and arises due to magnetic superzone effects. In the case of rare-earth metals such as Dy the resistivity shows a minimum followed by a maximum along the c axis before it decreases due to antiferromagnetic ordering.[5] This has been attributed to the magnetic superzone effect which arises because of the fact that the antiferromagnetic phase has a periodic arrangement along the c axis which is incommensurate with that of the lattice. However, such effects are not reported in intermetallic compounds. Only one paper[6] has observed this effect in substituted samples but not on an antiferromagnetic compound such as $Dy_5Ir_4Si_{10}$. If one assumes the oscillatory nature of $4f$ spins, the conduction electrons will experience a periodic potential whose period is incommensurate with that of the crystal lattice. This periodic potential, together with that of the lattice, produces gaps in the energy dispersion of conduction electrons. The magnetic superzone effect occurs when such a gap opens above T_N, leading to the reduction in carrier density, hence ρ shows a maximum, followed by a decrease in ρ below T_N due to a reduction in the spin-fluctuation scattering. Although our sample is a polycrystalline one, we see the magnetic superzone effect clearly in our compound. However, to compare with the theory it is essential to perform transport measurements in a single crystal of $Dy_5Ir_4Si_{10}$ and also the neutron-diffraction study to determine the reduced magnetic moment.

IV. CONCLUSION

We have established the AF state in $Dy_5Ir_4Si_{10}$ using dc susceptibility and resistivity measurements. The effective moment is equal to that of the free Dy ion. However, $\rho(T)$ data show a broad minimum at 17 K followed by a maximum at 6.5 K before starting to decrease below 6 K. It will be interesting to perform neutron-diffraction measurements on the single crystal of this sample which will determine the crystal-field levels and the actual magnetic moment carried by Dy.

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