Magnetism in the $R_5Ir_4Si_{10}$ (R = Ho and Er) systems

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In this paper we report the susceptibility and resistivity studies of $Er_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$. We find that these compounds undergo antiferromagnetic transitions at 2.5 and 2.0 K, respectively. The effective-moment calculated from the high-temperature susceptibility (Curie-Weiss plot) in each case is equal to the free-ion moment. However, the resistivity of both of these compounds show anomalous behavior in the temperature region 120–200 K, the origin of which is not understood. Similar behavior in resistivity is also seen in $Y_5Ir_4Si_{10}$, which is a superconductor at 3.0 K. Finally, the results are compared with that of an antiferromagnet $Dy_5Ir_4Si_{10}$.

I. INTRODUCTION

In the past many studies have been made on rare-earth silicides which exhibit both superconductivity and magnetism.[1] However, very few efforts[2] were made to study the magnetism in rare-earth iridium silicides ($R_5Ir_4Si_{10}$). Recently we have reported the antiferromagnetism in $Dy_5Ir_4Si_{10}$ and interesting resistivity (ρ) minima before T_n, which could be attributed to the superzone effects.[3] Previous studies indicate[4,5] that ρ of $Lu_5Ir_4Si_{10}$ shows anomalous behavior around 80 K which is attributed to spin-density wave (SDW) or charge-density wave (CDW) effects. In this paper we report the antiferromagnetic (AF) ordering in $Er_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$ at 2.5 and 2.0 K, respectively. This is done by measuring the magnetic susceptibility from 1.5 to 300 K. The temperature dependence of ρ shows an anomaly from 100 to 200 K in both compounds, whose origin is not understood. A similar anomaly is seen in $Y_5Ir_4Si_{10}$ which superconducts at 3.0 K.

II. EXPERIMENTAL DETAILS

The samples $Er_5Ir_4Si_{10}$, $Y_5Ir_4Si_{10}$, and $Ho_5Ir_4Si_{10}$ were made by melting the individual constituents in an arc furnance under high-purity argon atmosphere. The purity of Er, Y, Ho, and Ir is 99.9% while that of Si is 99.999%. The samples were 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 Faraday balance in a field of 4 kOe from 80 to 300 K and a home built ac susceptometer[6] was used in the temperature range from 1.5 to 100 K. The resistivity was measured using a four-probe dc technique and the contacts were made using ultrasonic solder (with nonsuperconducting solder) 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 Hewlett-Packard current source. The room-temperature and low-temperature (120 K) x-ray measurements were made using Cu K_α radiation in a JEOL (Japan) x-ray diffractometer. The temperature was stable within 0.5 K. The lattice constants decrease marginally with the decrease of temperature. The values of the lattice constants are given in Table I for room temperature and at 120 K.

III. RESULTS AND DISCUSSION

The temperature dependence of χ of $Er_5Ir_4Si_{10}$ from 1.3 to 300 K is shown in Fig. 1. The temperature dependence of χ from 1.5 to 20 K is shown in the inset. One can observe the AF transition from the inflection point (where $d^2\chi/dT^2=0$) at 2.5 K. Similar data for $Ho_5Ir_4Si_{10}$ from 1.5 to 5 K is shown in Fig. 2. Here one can see the AF transition at 2.0 K. However, a previous review[7] has incorrectly reported a ferromagnetic ordering for the Ho compound. From the absolute susceptibility values (see Fig. 2) and the inflection point in the susceptibility data at 2.0 K, we conclude that $Ho_5Ir_4Si_{10}$ undergoes AF transition below 2.0 K. The high-temperature χ (from 100 to 300 K) data fit well to the Curie-Weiss law

TABLE I. Structural properties of $R_5Ir_4Si_{10}$

R	a (Å)	c (Å)	ρ_{CAL} (x-ray) (g/cm^3)	ρ_{MEAS} (g/cm^3)	Temperature (K)
Er	12.4959	4.2499	9.45	9.44	300
Er	12.4927	4.2460	9.46	...	120
Ho	12.5540	4.1991	9.38	9.37	300
Ho	12.5417	4.1978	9.41	...	120

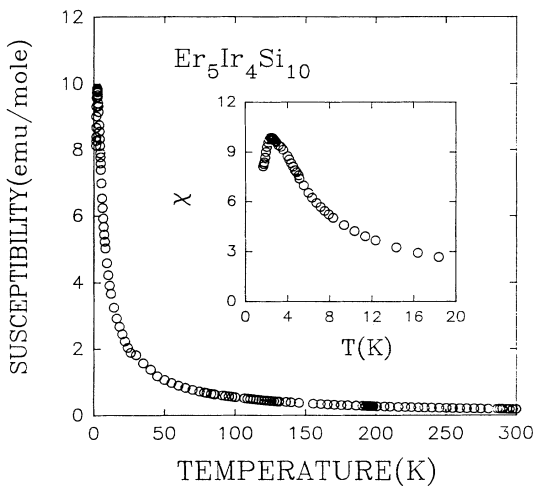

FIG. 1. Variation of susceptibility χ of $Er_5Ir_4Si_{10}$ from 1.5 to 300 K. The inset shows χ from 1.5 to 20 K.

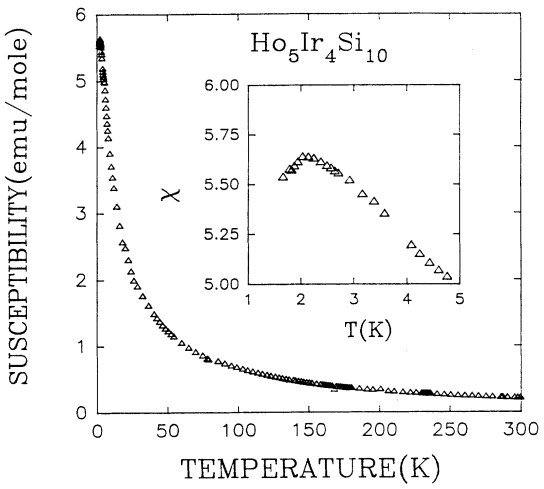

FIG. 2. Variation of susceptibility χ of $Ho_5Ir_4Si_{10}$ from 1.5 to 300 K. The inset shows χ from 1.5 to 5 K.

$[\chi(T)=C/(T+\theta_n)]$ for Er and Ho compounds as shown in Fig. 3. However, the value of θ_n for the Ho compound is negative which signifies that this compound might order ferromagnetically at low temperatures. Our low-temperature χ data reveal only the AF transition. The values of T_n, θ_n, C and μ_{eff} are given in Table II. The values of the μ_{eff} are close to the free-ion values. The values are compared with those of the previously established[3] antiferromagnet $Dy_5Ir_4Si_{10}$.

Resistivity Studies

The low-temperature resistivity ($1.5\ \text{K} < T < 12\ \text{K}$) of $Er_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$ are shown in Figs. 4 and 5, respectively. The complete temperature dependence of resistivity (ρ) for $Er_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$ from 1.5 to 300 K are shown in Figs. 6 and 7, respectively. The temperature region where each of the sample shows anomaly in ρ is shown in the inset. Here we find anomalous behavior of ρ in the temperature region from 100 to 200 K in both the samples. In this temperature range, the magnetic susceptibility does not show any anomaly (the data fit to the Curie-Weiss law). Hence we conclude that this behavior of $\rho(T)$ does not arise due to any magnetic contribution. Further, the $\rho(T)$ of $Y_5Ir_4Si_{10}$ also shows a similar anomaly (between 180 and 260 K) which can be seen in Fig. 8. It superconducts below 3.0 K which is in agreement with the data of Hausermann-Berg and Shelton[8] although their sample showed higher resistivity compared to ours. In order to understand whether the observed anomaly in ρ could arise due to structural transformation in these alloys, we have carried out low-temperature x-ray-diffraction measurements of $Er_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$ samples at 120 K. These samples did not show any structural transformation except for a slight decrease in the value of lattice constants which is given in Table I. We also did *not* see any additional peak or structural distortions which might signify a phase transition to another crystal symmetry. Hence it is unlikely that the observed anomaly in ρ could be driven by structural transformation in these alloys.

In the case of $Lu_5Ir_4Si_{10}$,[9] the anomaly in the resistivity has been explained due to the formation of charge-density waves. When such CDW form, energy gaps open at the Fermi surface at those portions which satisfy the nesting condition. The increase in the resistivity can be attributed to the decrease in area of the Fermi surface resulting from the opening of gaps. We believe that CDW also form in the other members of this structure (Er, Ho, and Y). Similar behavior has also been seen in $NbSe_3$.[10,11] Neutron-scattering and high-pressure experiments are necessary to study such transitions in detail.

IV. CONCLUSION

We have established the AF ordering in $Er_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$ at 2.5 K using dc and ac susceptibility and resistivity measurements. The effective moment in both cases is equal to that of the free-ion value. However, $\rho(T)$ data show anomalous behavior from 100 to 200 K which is not understood. Low-temperature x-ray-diffraction studies suggest that the observed anomaly in ρ

TABLE II. Magnetic properties of $R_5Ir_4Si_{10}$.

R	θ_n (K)	T_n (K)	C (emu/mole K)	μ_{eff}	μ_{free}	Ref.
Er	1.98	2.5	55.95	$9.5\mu_B$	$9.6\mu_B$	This work
Ho	−1.11	2.0	66.86	$10.3\mu_B$	$10.6\mu_B$	This work
Dy	18.14	5.0	73.79	$10.6\mu_B$	$10.6\mu_B$	Ref. 3

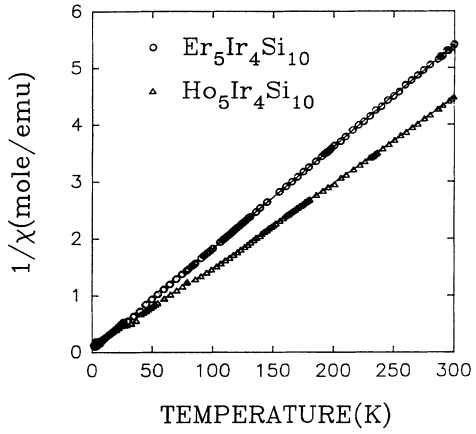

FIG. 3. Plot of $1/\chi$ with temperature from 1.5 to 300 K which shows the linear dependence from 100 to 300 K.

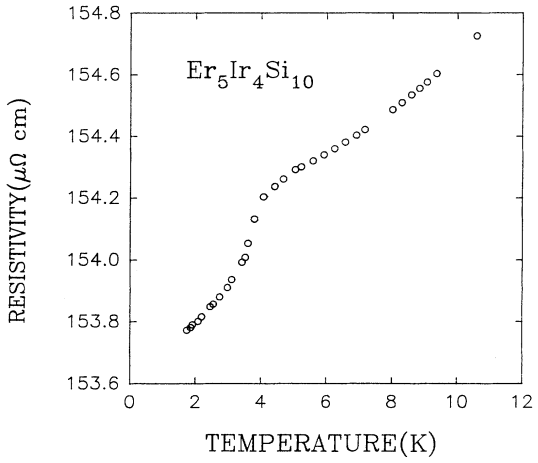

FIG. 4. Low-temperature dependence of ρ of $Er_5Ir_4Si_{10}$ from 1.5 to 12 K.

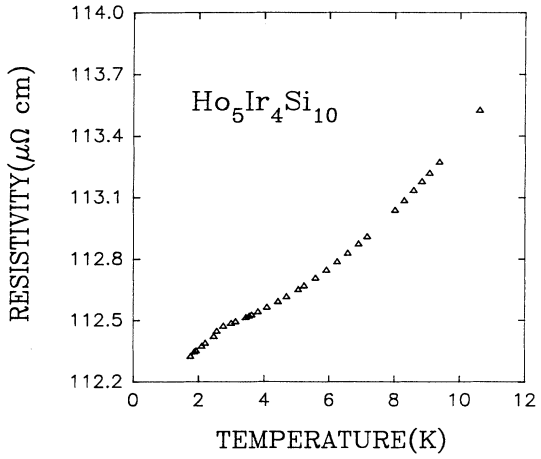

FIG. 5. Low-temperature dependence of ρ of $Ho_5Ir_4Si_{10}$ from 1.5 to 12 K.

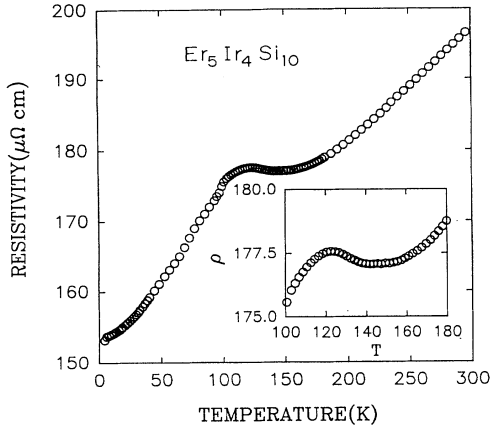

FIG. 6. Temperature dependence of $\rho(T)$ of $Er_5Ir_4Si_{10}$ from 1.5 to 300 K. The inset shows the dependence of $\rho(T)$ of $Er_5Ir_4Si_{10}$ from 100 to 180 K.

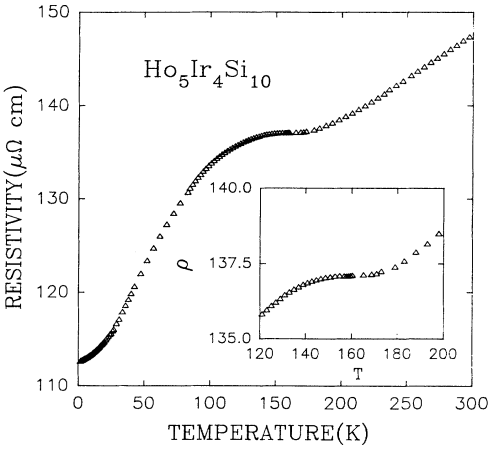

FIG. 7 Temperature dependence of $\rho(T)$ of $Ho_5Ir_4Si_{10}$ from 1.5 to 300 K. The inset shows the $\rho(T)$ of $Ho_5Ir_4Si_{10}$ from 120 to 200 K.

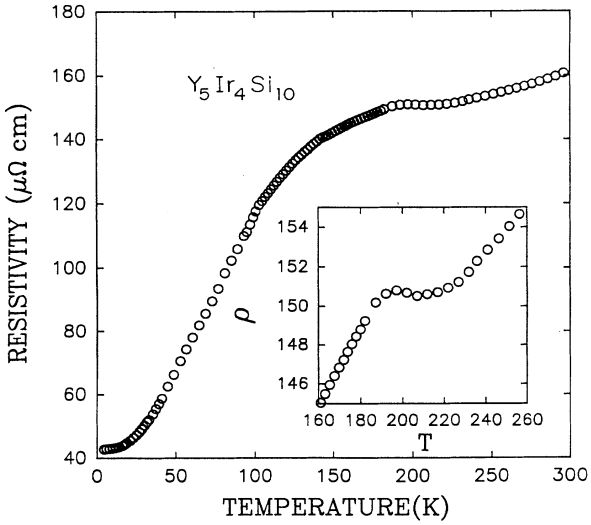

FIG. 8. Temperature dependence of $\rho(T)$ of $Y_5Ir_4Si_{10}$ from 1.5 to 300 K. The inset shows the $\rho(T)$ of $Y_5Ir_4Si_{10}$ from 160 to 260 K.

is unlikely to be due to structural transformation in these alloys. The anomaly is attributed to the formation of CDW which opens a gap in the Fermi surface. It will be interesting to do neutron-diffraction measurements on the single crystals of these samples which will determine the crystal-field levels and the actual moment carried by Er and Ho. Such a study will also help us in understanding the anomalous behavior in $\rho(T)$ of these compounds.

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