Anomalous properties of single-crystalline lutecium stannide

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The electrical resistivity of a ternary intermetallic compound $LuRh_{12}Sn_4$ is studied. The reasons for the anomalous temperature and magnetic-field dependences of the electrical resistivity are discussed.

Thus far, the electron-electron interaction and localization in 3D metals were observed only in amorphous systems (see, e.g., Ref. 1). In this letter we report the first observation of these effects in single-crystal samples. We chose to study lutecium stannide, which was initially synthesized by Remeika *et al.*[2] The single-crystal samples were grown by the molten-solution method. The electrical resistivity ρ was measured by the standard four-contact method.

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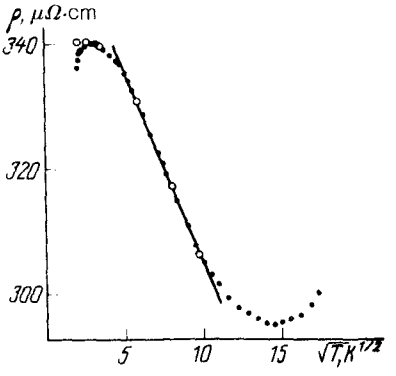

FIG. 1. Temperature dependence of the resistivity ρ of lutecium stannide. ●—$H = 0$; ○—$H = 55$ kG.

The temperature dependence of ρ is shown in Fig. 1. We see in Fig. 1 that the ρ dependence has a nonmetallic nature over a broad temperature range. At $T \gtrsim 10$ K a ~ 55-kG magnetic field has no effect on the resistivity, which appears to indicate that the anomaly which is observed has a nonmagnetic nature. A positive magnetoresistance is observed at lower temperatures. Figure 2 is a plot of the magnetoresistivity as a function of the magnetic field.

The mean free path l of the conduction electrons estimated from the electrical resistivity shows that it is on the order of the atomic spacing (3 Å). Such a short l and a positive magnetoresistance allow one to assume that the temperature dependence ρ observed stems from the interference of electron-electron interaction and elastic scattering by static inhomogeneities,[3] whose contribution to $\Delta\rho(T)$ at $T_c < T - T_c < \tau^{-1}$ (τ is the momentum transit time of the conduction electrons) is greater than that of the superconducting fluctuations,[4] whereas the magnetoresistance is primarily fluctuational in nature. According to the results of Ref. 5, the magnetoresistance can be

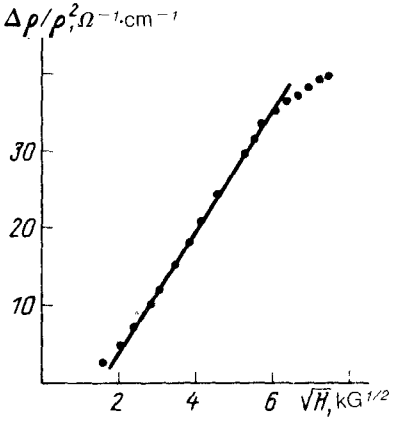

FIG. 2. Magnetoresistance of lutecium stannide versus the magnetic field at $T = 4.2$ K.

written in the form

$$\frac{\Delta\rho(H)}{\rho^2} = \frac{e^2}{2\lambda^2\hbar}\left(\frac{eH}{\cosh}\right)^{1/2} f_3(\tilde{\omega}_c\tau_\varphi)\,\beta(T)\,, \qquad (1)$$

where

$$f_3(x) = \begin{cases} x^{3/2}/48 & \text{for } x < 1 \\ 0.605 & \text{for } x > 1 \end{cases} \qquad \tilde{\omega}_c = 4DeH/\hbar c\,.$$

Here D is the diffusion coefficient of the conduction electrons, and τ_ϕ is the phase relaxation time of the conduction-electron wave function; this time is governed by the inelastic collisions. In Eq. (1) the localization contribution to $\Delta\rho(H)$ is omitted, which corresponds to $\beta(T) \gg 1$.

The experimental data on the magnetoresistance (Fig. 2) are described well by expression (1). In low magnetic fields (up to 4 kG), for example, we have $\Delta\rho/\rho^2 \sim H^2$, but upon reaching the quantum limit ($\tilde{\omega}_c\tau_\varphi > 1$) the magnetoresistance can be written in the form $\Delta\rho/\rho^2 = \alpha\sqrt{H}$. The experimentally obtained value of the coefficient α is 11.1 $(\text{kG}\cdot\Omega\cdot\text{cm})^{-1}$. From Eq. (1) we then find $\beta(4.2\text{ K}) = 12$, which corresponds, according to the data of Ref. 6, to the superconducting transition temperature $T_c = 3.6$ K. This value is approximately equal to the value actually measured for the given compound[2]: $T_c = 3.9$ K.

The temperature contribution to the resistivity, which is associated with the diffusion-channel interaction, is [3,7]

$$\frac{\Delta\rho(T)}{\rho^2} = -0.915\,\frac{e^2}{3\lambda^2\hbar}\left(1 - \frac{9}{8}\nu\Gamma_2\right)\left(\frac{kT}{\hbar D}\right)^{1/2} \qquad (2)$$

where Γ_2 is the amplitude for scattering of quasiparticles through a large angle, and ν is the density of states. The observable temperature dependence of the electrical resistivity (Fig. 1) can be described by expression (2) for $D \cong 0.003$ cm^3/s. Such a small diffusion coefficient of the conduction electrons is attributable to a strong disorder of the structure of the compound that has been studied: The places of the regular system of points in the single crystal are randomly occupied by different types of atoms. The diffusion coefficient in this case acquires temperature-independent localization and interference corrections which greatly reduce its value.

In summary, the giant anomalies of the electrical resistivity of the single-crystal compound $LuRh_{1.2}Sn_4$ observed by us can be understood in terms of the present knowledge of the conductivity of disordered systems.

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