LOW TEMPERATURE MAGNETORESISTANCE OF NEARLY MAGNETIC TRANSITION-METAL BASED ALLOYS AND ACTINIDES

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We calculate the relative change of the electrical resistance of nearly magnetic transition-metal based alloys and actinides due to the presence of a magnetic field. Theoretically, these alloys are described by the Wolff hamiltonian and most of their properties can be explained by assuming[1] that the dominant scattering process in these systems is scattering of the conduction electrons on the fluctuations of the local magnetiation at the impurity site (LSF approximation).

At low temperature the magnetoresistance can be written as $\rho^{-1}(T,H) \simeq \tau_{\uparrow}(\varepsilon_F) + \tau_{\downarrow}(\varepsilon_F)$, where $\tau_{\sigma}(\varepsilon_F)$ is the spin dependent (relacation time of conduction electrons ($\sigma=\uparrow\downarrow$) and T,H,ε_F are temperature, external field and the Fermi energy of the system. For dilute alloys, τ_σ is simply related to the conduction electrons scattering matrix T_σ, $\tau_\sigma \simeq -\mathrm{Im} T_\sigma$. In the Wolff model one has

$$T_\sigma = \frac{W + \Sigma_\sigma}{1 - G^0_\sigma (W + \Sigma_\sigma)} , \qquad (1)$$

where W is the normal one-body impurity potential (neglected in what follows), Σ_σ is the spin-dependent many-body part of the electrons self-energy, $G^0_\sigma = (\varepsilon \mp H - i\Gamma)^{-1}$ is the unrenormalised conduction electrons Green function and Γ is the width of the conduction band. In the LSF approximation[1], Σ_σ is given by the (for up spin electrons)

$$\Sigma_{\uparrow}(\varepsilon) = T \sum_B G^0_{\downarrow}(\varepsilon - i\omega_B)\, \chi^{+-}(i\omega_B) , \qquad (2)$$

where summation goes over all the Bose frequences ω_B and $\chi^{+-}(\varepsilon)$ describes the fluctuations of the local magnetiation. Propagator χ^{+-} has a simple analytical structure[2] which, in the presence of the magnetic field can be written as

$$\chi^{+-}(\varepsilon) = \pi \Gamma^2 \frac{1}{T_K \mp i(\varepsilon + H)} \tag{3}$$

Although the form of χ^{+-} is reminiscent of the RPA result, here χ^{+-} is taken as a phenomenological expression and the LSF temperature T_K is given by the experiment.

Evaluating sum over ω_B[3], we obtain for $\Sigma_\uparrow$ (assuming $T, H \ll T_K$)

$$\begin{aligned} H + \mathrm{Re}\,\Sigma_\uparrow &= \Gamma\left(\frac{H}{T_K}\right)\left[1 - \pi\frac{T}{T_K} - \frac{\pi^2}{3}\left(\frac{T}{T_K}\right)^2 + \cdots\right] \\ \Gamma - \mathrm{Im}\,\Sigma_\uparrow &= \Gamma\left[1 + \frac{\pi^2}{2}\left(\frac{T}{T_K}\right)^2 + \cdots\right] . \end{aligned} \tag{4}$$

Corresponding expression for down spin electrons is obtained in the analogous way and from (4) and (1) we get for the relative change of the magnetoresistance

$$\frac{\Delta\rho(H,T)}{\rho_0(T)} = \frac{2}{\pi^2}\left(\frac{H}{T_K}\right)^2\left[1 - 2\pi\frac{T}{T_K} - \frac{\pi^2}{2}\left(\frac{T}{T_K}\right)^2\right] , \tag{5}$$

where $\rho_0(T)$ is the zero-field resistance[1]. In the general case (T not small with respect to T_K) we evaluate $\Delta\rho/\rho_0$ by numerical integration and obtain the interesting result that $\Delta\rho/\rho_0$ becomes negative above certain temperature T_0 ($T_0 < T_K$). Above T_0, the magnetoresistance decreases with the increasing temperature and tends to zero for $T > T_K$. Full discussion of these result and their application to the magnetoresistance measurements in actinide systems will be subject of a separate publication.

References:

1) N.Rivier and V.Zlatić, J.Phys.F2, L99(1972)
2) V.Zlatić,G.Grüner and N.Rivier, Solid State Comm.14,639(1974)
3) A.A.Abrikosov, L.P.Gorkov and L.I.Dzyaloshinskii, "Quantum field theoretical methods in statistical physics" (Pergamon, London, 1965)