Equation (7) is analogous to the area rule in the theory of strong-field domains [10]. It follows from (7) that with increasing E the maximum pair concentration in the pinch decreases. The pinch dimension is proportional to the "generation-diffusion length" $(D_p g_\infty^{-1})^{1/2}$ and increases with increasing E. An investigation of the system (3) - (4) with allowance for (7) also shows that the excitation of the pinch is hard and that hysteresis exists between the threshold currents at which the pinch appears and disappears.

Interesting phenomena should occur when the sample with the pinch is placed in an external magnetic field H perpendicular to the plane of the pinch. The instability then changes from absolute to convective. The pinch begins to drift towards the wall of the sample, with a velocity V_H on the order of $\mu_n \mu_p EH/c$. The physical mechanism of the pinch motion is as follows: the holes, which are much heavier and less mobile than the electrons, move in the Hall field of the electrons (just as in the Suhl effect). They are followed by the electrons, in order to maintain the electric neutrality. If the rate V_S of the surface recombination is small compared with V_H, the pinch stops at the wall of the sample. When $V_S > V_H$, the pinch vanishes at the wall, after which a new pinch is produced at the center of the sample and the cycle is repeated. In this case, voltage oscillations should be observed in the external circuit, at frequencies on the order of V_H/a (a - transverse dimensions of the sample); these frequencies are much lower than the Gunn generation frequency.

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ANOMALOUS THERMOELECTRIC POWER OF FERROMAGNETIC METALS WITH MAGNETIC IMPURITIES

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Scattering of electrons by magnetic impurities in ferromagnetic metals, together with scattering by magnons, can lead to an anomalously large thermoelectric power, commensurate with k/e. The cause of this fact can be qualitatively explained as follows. An electron with a spin in the same (opposite) direction as the magnetic moment ↑(↓) can only absorb (emit) a magnon. Therefore, as a result of the single-magnon process, an electron with spin ↑(↓) and with energy ε higher (lower) than the Fermi level ε_F can go over into the region above (below) the Fermi surface, and by the same token change the direction of the drift under the incluence of the temperature gradient, whereas an electron with spin ↑(↓) and energy higher (lower) than ε_F does not change its drift direction in the single-magnon process; in other words, the effective relaxation time of electrons with a given spin is not an even function of $\varepsilon - \varepsilon_F$. Thus, each of the groups of electrons with spin ↑ and ↓ makes a contribution

(with opposite sign) to the thermoelectric power even in the zeroth order in the parameters T/ε_F and I/ε_F, where I is the energy of the electron-magnon exchange interaction. If the times of relaxation of electrons with spins ↑ and ↓ on the magnetic impurities are also different, then these contributions do not cancel each other.

We now proceed to calculate the thermoelectric power. The scattering of the electrons by the magnons, as usual, will be described with the aid of the Hamiltonian of the s-d exchange interaction [1]. The non-equilibrium additions to the distribution functions of the electrons with spins ↑ and ↓ satisfy a system of kinetic equations containing the terms corresponding to the collisions of the electrons with the magnons [2, 3] and of the electrons with the magnetic impurities[1]. The scattering of the electrons by the magnetic impurities will be described by the relaxation times $\tau_\uparrow$ and $\tau_\downarrow$, which can differ greatly from each other [4, 5].

We consider the temperature region bounded from below by the temperature

$$T_0 = \frac{S^2}{4}\,\frac{I}{\varepsilon_F}\,\frac{m}{\mu}\,\frac{I}{k} \approx \left(\frac{I}{\varepsilon_F}\right)^2 T_c$$

below which the single-magnon scattering of the electrons is ineffective [2, 6], and bounded from above by the temperature at which the phonon scattering begins to prevail over the impurity scattering. In the expression for T_0, S is the spin of the matrix ion, m the electron mass, μ the magnon mass, and T_c the Curie temperature.

Assuming for simplicity that the electron spectrum is isotropic, we seek the non-equilibrium additions f_{ip} (i = ↑, ↓; p - electron momentum) in the form

$$f_{ip} = -\left(u_i^{(1)} + u_i^{(2)}\,\frac{\epsilon-\epsilon_F}{T}, p\right)\frac{\partial n}{\partial \epsilon}, \qquad (1)$$

where $u_i^{(1)}$ and $u_i^{(2)}$ do not depend on the electron energy, n is the equilibrium distribution function. Then the kinetic equations reduce to a system of four algebraic equations relative to $u_i^{(1)}$ and $u_i^{(2)}$. Neglecting the terms proportional to I/ε_F and T/T_c compared with $|I - \tau_\uparrow/\tau_\downarrow|$, we obtain the following expression for the thermoelectric power[2]

$$\alpha = \frac{\pi^2 k}{3e}\,\frac{u_\uparrow^{(2)} + u_\downarrow^{(2)}}{u_\uparrow^{(1)} + u_\downarrow^{(1)}} = \frac{\pi^2 k}{3e}\,\frac{r_\uparrow - r_\downarrow}{2r_s + A(r_\uparrow + r_\downarrow) + B r_\uparrow r_\downarrow r_s^{-1}}, \qquad (2)$$

where

$$A = 2 + \frac{9\zeta(3)}{\pi^2} + 2\ln\frac{T}{T_0} \approx 3{,}1 + 2\ln\frac{T}{T_0},$$

$$B = \frac{36\zeta(3)}{\pi^2} - \frac{2\pi^2}{3} + \frac{36\zeta(3)}{\pi^2}\ln\frac{T}{T_0} \approx 2{,}2\left(2\ln\frac{T}{T_0} - 1\right),$$

[1] The scattering of the electrons by the nonmagnetic effects and phonons is assumed to be small compared with the scattering by the magnetic impurities.

[2] The discarded terms determine the thermoelectric powers of the ferromagnetic metals at low temperatures in the absence of magnetic impurities [2, 3].

and $\zeta(3)$ is the Teimann function. The electron-magnon energy-relaxation time [2] is

$$\tau_s = \left(\frac{\epsilon_F}{l}\right)^2 \frac{m}{\mu} \frac{4\pi\hbar^3}{p_F^3 \Omega S} \frac{\hbar}{kT} \sim \left(\frac{\epsilon_F}{l}\right)^2 \frac{\hbar T_c}{\epsilon_F T}. \tag{3}$$

Here Ω is the volume of the unit cell.

If $\tau_s \gg \tau_\uparrow, \tau_\downarrow$ we have

$$\alpha = \frac{\pi^2 k}{6e} \frac{\tau_\uparrow - \tau_\downarrow}{\tau_s} \sim T. \tag{4}$$

When $\tau_s \ll \tau_\uparrow, \tau_\downarrow$ we have

$$\alpha = \frac{\pi^2 k}{3eB} \frac{\tau_s(\tau_\uparrow - \tau_\downarrow)}{\tau_\uparrow \tau_\downarrow} \sim T^{-1}. \tag{5}$$

The thermoelectric power reaches a maximum

$$\alpha_{max} = \frac{\pi^2 k}{3e} \frac{\tau_\uparrow - \tau_\downarrow}{A(\tau_\uparrow + \tau_\downarrow) + 2\sqrt{2B\tau_\uparrow \tau_\downarrow}} \tag{6}$$

when

$$t_s = \sqrt{\frac{B}{2} \tau_\uparrow \tau_\downarrow}. \tag{7}$$

The largest value of $|\alpha_{max}|$ is reached when $\tau_\uparrow \gg \tau_\downarrow$ or $\tau_\uparrow \gg \tau_\downarrow$, and then

$$|\alpha_{max}| = \frac{\pi^2 k}{3|e|A} \sim \frac{k}{|e|}. \tag{8}$$

The sign of the thermoelectric power, as seen from (2) is determined by the sign of the difference $\tau_\uparrow - \tau_\downarrow$, i.e., it depends on the impurity, in accord with [4, 5].

There are grounds for assuming that the experimentally observed electron scattering with spin flip is determined just by the electron-magnon interaction [6]. The available experimental data on the times τ_s ($\simeq \tau_{\uparrow\downarrow}$ from [6]), $\tau_\uparrow$, and $\tau_\downarrow$ give grounds for hoping that the condition for the maximum thermoelectric power (7) can be satisfied at low defect concentration. For example, in Ni with 1 at.% Co added, the time τ_s becomes comparable with $\tau \simeq (13 - 30)\tau_\downarrow$ at T $\simeq$ 40°K [4, 5]. Thus, condition (7) can be satisfied by decreasing the Co concentration several-fold.

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