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Quantum $3D{-}2D$ dimensional crossover in quasi-one-dimensional layered conductors

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We theoretically analyze forbidden in the Fermi liquid theory magnetization of a layered quasi-one-dimensional (Q1D) conductor with open electron Fermi surfaces. We consider the most principle case, where the quasi-classical "sizes" of electron trajectories are less than the distances between conducting planes, i.e. under condition of the so-called quantum $3D \to 2D$ dimensional crossover. We suggest to investigate experimentally the above mentioned phenomenon (which is due to the electron-electron interactions of low-dimensional electrons) in a metallic phase of the layered Q1D conductor $(\mathrm{Per})_2\mathrm{Au(mnt)}_2$.

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In layered Q1D and Q2D conductors a number of unusual phenomena is observed due to the so-called quasi-classical $3D \to 2D$ and $3D \to 1D$ dimensional crossovers in a magnetic field. Among them, are the Field Induced Spin (Charge) Density Waves, Lebed Magic Angles, Danner–Chaikin and Lee–Naughton–Lebed oscillations [1–4]. The main feature of the experimentally observed effects is quasi-classical nature of the corresponding dimensional crossovers, where the typical "sizes" of electron trajectories in a magnetic field are bigger than the inter-layer, $d_\perp$, and inter-chain, $d_\parallel$, distances:

$$l_\perp(H) \gg d_\perp \tag{1}$$

and

$$l_\parallel(H) \gg d_\parallel. \tag{2}$$

Nevertheless, as was suggested by Lebed [5, 6] and Lebed and Yamaji [7], there are possible quantum $3D \to 2D$ dimensional crossovers, characterizing by the equation

$$l_\perp(H) \leq d_\perp. \tag{3}$$

In this case, electron wave functions are localized near conducting planes and novel phenomenon – Reentrant superconductivity – is possible [5–7]. Unfortunately, the above mentioned phenomenon has not been observed in full, although some possibility of the Reentrant superconductivity in UTe_2 have been discussed [8–10].

The goal of our Letter is to suggest another non Fermi liquid effect, which can be observed under the condition of the quantum $3D \to 2D$ dimensional crossover (3) in high parallel magnetic fields in layered quasi-one-dimensional (Q1D) conductors. We show that in this case unexpected temperature dependent magnetization appears in Q1D metal with open Fermi surfaces due to electron-electron interactions which depend on a magnetic field. It is proposed by us to be measured in the layered Q1D conductor $(\mathrm{Per})_2\mathrm{Au(mnt)}_2$, which can be done in feasibly high magnetic fields, $H \simeq 20{-}30\,\mathrm{T}$. First, such experiments can discover the above mentioned non Fermi liquid effect, second, it would be an experimental discovery of the dimensional crossover (3).

In this Letter, we use an orthorhombic model of unit cell of a layered Q1D conductor, where its electron Fermi surface in tight binding model can be written as

$$\epsilon^{\pm}(\mathbf{p}) = \pm v_F(p_x \mp p_F) + 2t_b \cos(p_y b^*) + 2t_c \cos(p_z c^*), \tag{4}$$

where $v_F p_F \gg t_b \gg t_c$; v_F is the Fermi velocity, p_F is the Fermi momentum; $\hbar = 1$; signs $(+)$ and $(-)$ stand for the right and left sheets of the Fermi surface, respectively. Let us study $3D \to 2D$ dimensional crossover of Q1D spectrum (4) in the perpendicular magnetic field,

$$\mathbf{H} = (0, 0, H), \quad \mathbf{A} = (0, Hx, 0). \tag{5}$$

After application of Green's function method [2,11] for electron-electron interactions in the magnetic (5) we obtain the following expression for extra magnetic momentum:

$$MH = \frac{4g^2 t_b^2}{p_F v_F} N(t), \tag{6}$$

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where

$$N(t) = t^3 \int_0^\infty \frac{\cosh(ty)}{\sinh^3(ty)} \sin(y)[\sin(y) - y\cos(y)]. \quad (7)$$

Let us calculate the integral $N(t)$ (7) numerically. The result of such calculations is shown in Fig. 1, where (7)

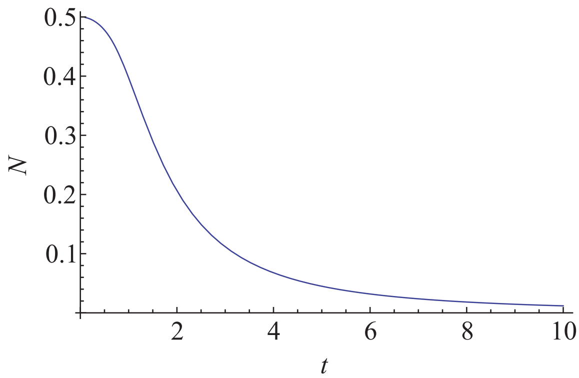

Fig. 1. (Color online) Numerical calculations of the integral (7) as a function of normalized temperature, $t = \frac{4\pi T}{\omega_c}$

is calculated as a function of normalized temperature $t = \frac{4\pi T}{\omega_c}$. Note that magnetic moment (6) and (7) can be larger or smaller than the conventional Zeeman term,

$$M_0 = 2\frac{(\mu_B)^2 H}{p_F v_F}. \quad (8)$$

Let us estimate at low temperatures the suggested extra magnetic moment in terms of paramagnetic moment M_0 at $H = 20\,\mathrm{T}$, using Eqs. (6)–(7) and value $t_b = 20\,\mathrm{K}$ [12]:

$$M = 2.5 g^2 M_0 \sim M_0. \quad (9)$$

The unique property of (6) and (7) is that corresponding magnetic momentum is strongly temperature dependent (see Fig. 1). The suggested effect is based on quantum nature of electrons motion in a magnetic field and, thus, it disappears at high enough temperatures, $t \geq 1$.

To summarize, we suggest to measure temperature dependence of the magnetic moment in a metallic phase of the layered Q1D conductor $(\mathrm{Per})_2[\mathrm{Au(mnt)}_2]$ to discover non Fermi liquid effect, suggested in the Letter. Let us do some comments of experimental importance. The notations of the axes **a** and **b** in the above mentioned compound are different from the standard ones [1] used in the Letter. To satisfy condition of our calculation magnetic field has to be applied along **c** axis. Moreover, condition of the 2D crossover (see (3)) is reached at feasibly high magnetic fields,

$$H \gg 10\,\mathrm{T}, \quad (10)$$

where we have used for the estimations $v_F = 1.7 \times 10^7\,\mathrm{cm/s}$ and $b^* = 16.6 \times 10^{-8}\,\mathrm{cm}$ [12].

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Conflict of interest. The author of this work declares that he has no conflicts of interest.

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