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Non Fermi-Liquid magnetoresistance oscillations in quasi-one-dimensional conductors

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We theoretically demonstrate that strong non Fermi-liquid magnetic oscillations of electron–electron scattering time can exist in quasi-one-dimensional conductors under condition of the magnetic breakdown between two open electron orbits. They are shown to be due to electron–electron interactions in a metallic phase under condition of the magnetic breakdown and they are beyond the Fermi-liquid theory. In particular, we consider as example the organic conductor $(TMTSF)_2ClO_4$ and perform both analytical and numerical calculations for its known electron spectrum. We also argue that similar oscillations of resistivity can exist in a metallic phase of another quasi-one-dimensional organic conductor – $(Per)_2Au(mnt)_2$.

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Quasi-one-dimensional (Q1D) layered organic conductors exhibit very rich and unusual properties in a magnetic field both in their Field-Induced Spin(Charge)-Density-Wave (FIS(C)DW) and metallic phases (for a review, see book [1]). Among them, the conductors $(TMTSF)_2ClO_4$ and $(TMTSF)_2PF_6$ demonstrate the existence of the so-called Rapid Magnetic Oscillations (RMO). It is important that in $(TMTSF)_2PF_6$ the RMO exist only in FISDW phase [2–5], whereas in the $(TMTSF)_2ClO_4$ they are observed both in FISDW and metallic phases [6–11] (see recent [11] and references therein). Yan et al. [7] first related the appearance of the RMO in the $(TMTSF)_2ClO_4$ to the existence of the so-called interference breakdown electron orbits [12, 13] in the $(TMTSF)_2ClO_4$. Theory of the RMO in the FISDW phase was successfully created [14–17] by using the above mentioned idea. Yan et al. [7] also related the experimentally observed RMO in a metallic phase along **y** axis to one-body effect – the so-called Stark interference between the interference electron orbits. On the other hand, it was stressed [18], that the RMO in resistivity along the conducting chains in a metallic phase of the organic conductor $(TMTSF)_2ClO_4$ cannot be explained just by one-body magnetic breakdown through the interference trajectories since the magnetic breakdown happened in the perpendicular to the chain direction. It was suggested [18] that non Fermi-liquid oscillations of the Umklapp electron–electron scattering time under condition of the magnetic breakdown could, in principal, explain the experimental observations. As to Q1D conductor $(TMTSF)_2PF_6$, which doesn't exhibit the magnetic breakdown, RMO in its FISDW have different physical origin and may be explain in terms of the coexistence of two FISDW's [2–5, 19]. It is important that this second type of the RMO is also discovered in FISDW phase of $(TMTSF)_2ClO_4$ [20].

The goal of our Letter is to make the exotic suggestion of [18] more realistic and more suitable for its comparison with the existing experiments [6–11] as well as for the possible future experiments. First of all, here we consider the realistic Q1D spectrum of the $(TMTSF)_2ClO_4$, instead of 2D spectrum of [18]. In addition we perform numerical calculations of the obtained results, instead of very rough estimations done in [18]. Our conclusion is that non Fermi-liquid oscillations of electron–electron scattering time can account for the RMO observed in a metallic phase, although further experiments are needed. We also suggest another candidate for discovery of non Fermi-liquid oscillations of longitudinal resistivity under the condition of the magnetic breakdown – Q1D organic conductor $(Per)_2Au(mnt)_2$ under pressure in a metallic phase [21].

Let us consider Q1D electron spectrum of the organic conductors $(TMTSF)_2ClO_4$ in the presence of the so-called anion ordering gap. It can be written in tight-binding orthorhombic model as [1]

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$$\epsilon_n^{\pm}(\mathbf{p}) = \pm v_F(p_x \mp p_F) + (-1)^n \sqrt{[2t_b \cos(p_y b^*)]^2 + \Box^2} + \\ + 2t_c \cos(p_z c^*), \quad n = 1, 2, \tag{1}$$

where $p_F \parallel x$, $b^* \parallel y$, and $c^* \parallel z$; $v_F p_F \gg t_b \gg \gg t_c$, $\Box \ll 2t_b$. It is important that the Eq. (1) corresponds to the experimental situation in the conductor $(TMTSF)_2ClO_4$ at ambient pressure.

At high magnetic fields, the magnetic breakdown phenomenon through the anion gap, $\Box$, occurs between two open sheets of the Fermi surfaces denoted by $n = 1$ and $n = 2$ in Eq. (1).

By means of variational principle for Boltzmann kinetic equation for electron–electron scattering, we obtain for the resistivity along the conducting chains [18]:

$$\rho(H) \sim \frac{1}{\tau}(H) = g^2 T \int_{-\infty}^{\infty} dx \frac{2\pi T/v_F}{\sinh^2(2\pi T x/v_F)} \times \\ \times \left[\frac{2\pi T|x|/v_F}{\exp(4\pi T|x|/v_F) - 1} + \frac{2\pi T|x|/v_F - 1}{2}\right] \times \\ \times \int_{-\pi}^{\pi} \frac{d\phi_1}{2\pi} \int_{-\pi}^{\pi} \frac{d\phi_2}{2\pi} J_0^2[(4t_c x/v_F)\sin(\phi_1)] \times \\ \times \left\{ J_0^2\left[2\lambda \sin\left(\frac{\omega_b x}{2v_F}\right)\sin(\phi_2)\right]\cos^4\left(\frac{\Box^* x}{v_F}\right) + \\ + J_0^2\left[2\lambda \cos\left(\frac{\omega_b x}{2v_F}\right)\cos(\phi_2)\right]\sin^4\left(\frac{\Box^* x}{v_F}\right)\right\}. \tag{2}$$

We stress that in [18] the magnetoresistance was very roughly estimated in the absence of $J_0^2[(4t_c x/v_F)\sin(\phi_1)]$ term in Eq. (2) (i.e., in the absence of electron energy dependence along $\mathbf{z}$ axis). Here we evaluate the entire integral (2) numerically in the interval of magnetic fields of 40–75 T, which are much higher than the breakdown magnetic field, experimentally estimated as 10–15 T [6–9]. For numeric calculations of Eq. (2), we use the following values of the parameters: $t_b = 200\,\text{K}$, $t_c = 5\,\text{K}$, $\Box = 50\,\text{K}$, $v_F = 2 \times 10^7\,\text{cm/s}$, $b^* = 7.7\,\text{Å}$, $c^* = 13.6\,\text{Å}$ [1]. We perform calculations for high enough temperature $T = 10\,\text{K}$, which corresponds to stabilization of a metallic phase in $(TMTSF)_2ClO_4$ [6–11]. As seen from Fig. 1, relatively large magnetoresistance oscillations,

$$\frac{\delta\rho}{\rho} \geq 10^{-2}, \tag{3}$$

can, indeed, exist in high magnetic fields in $(TMTSF)_2ClO_4$ organic conductor.

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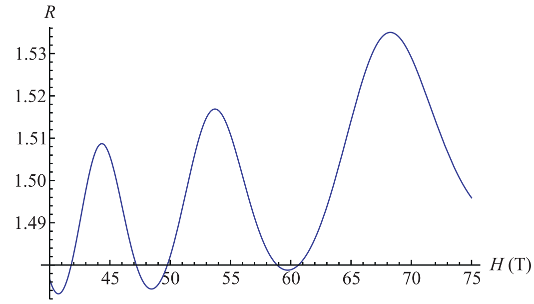

Fig. 1. (Color online) Numerically calculated resistivity, including resistivity oscillations, along the conduction chains is shown (see Eq. (2))

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

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