# Electrodynamics of exciton pairing in low-dimensionality crystals without inversion centers

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We demonstrate the existence of diamagnetic currents in quasi-one-dimensional and quasi-two-dimensional (layered) crystals with two types of carrier and a structure where $p$ and $n$ layers alternate (strings).

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Exciton pairing of electrons and holes in a degenerate semimetal with two types of carrier was first considered by Keldysh and Kopaev[1] and was subsequently investigated in a number of studies. The electrodynamics of such systems was investigated in[2]. Lozovik and Yudson[3] have advanced the interesting hypothesis that carriers of opposite sign are paired in sandwiches of semimetals of $p$ and $n$ type.[1)] The purpose of this paper is to consider exciton pairing in low-dimensionality crystals, for example of the type of salts with charge transfer TTF-TCNQ,[5] or layered compounds with regions of electron and hole conductivity, so arranged that the interaction of the closest $p$ and $n$ layers (strings) exceeds the interaction between neighboring pairs of layers (see the figure). Such a system has no inversion center and is characterized by a vector $\mathbf{a}_0$ perpendicular to the alternation direction. It will be shown that the magnetic properties of such structures are quite different from those of the "excitonic insulator" of the usual type.

We consider a pair of closely-lying layers 1 and 2. The currents flowing in these layers below the point of excitonic transitions are given by the relations

$$J_1 = nev_s, \qquad J_2 = -nev_s, \tag{1}$$

where $v_s$ is the "superfluid velocity" or the exciton velocity due to the pairing of spatially separated carriers of $p$ and $n$ type.[3,4] If a magnetic field $H$ is applied parallel to the layers (see the figure), then the exciton equation of motion is

$$M\frac{dv_s}{dt} = e(E_1 + E_2), \tag{2}$$

the induction law yielding $L(E_1+E_2)=(-1/c)(\partial\Phi/\partial t)$, where $\Phi=(A_1-A_2)L$ is the flux crossing the space between the nearest layers, $M=m_1+m_2$ is the total mass of the electron and hole, and $A_1$ and $A_2$ are the values of the vector potential in the layers. Integrating this relation, we obtain

$$J_1 = -J_2 = \frac{ne^2}{Mc}(A_1 - A_2). \tag{3}$$

This relation was derived more rigorously in[4] by solving the system of Gor'kov's equations for the exciton pairing. At a finite temperature, $n$ is the "concentration of the superconducting electrons," $n=n_s(T)$, and depends on $T$ in the same manner as the corresponding function in a superconductor.

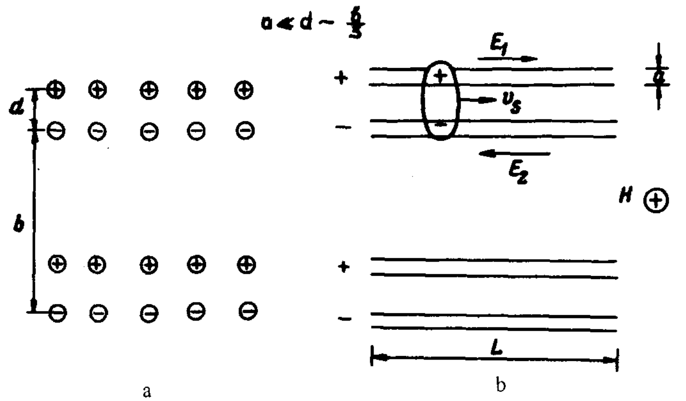


FIG. a) Quasi-one-dimensional crystal, b) layered crystal.

The double current layer produces a magnetic moment $\mu=IS/c$, where $S$ is the area over which the current flows. This leads to diamagnetism of the low-dimensionality crystal with dielectric pairing of the indicated type. The magnetic susceptibility is

$$\chi = -\frac{ne^2}{Mc^2}\frac{ad^2}{b}, \tag{4}$$

where $a$ is the effective thickness of the layer, $d$ is the distance between layers, and $b$ is the distance between pairs of layers. At $n \sim 10^{23}$ cm$^{-3}$, $M \sim m_0$, and $a \sim d \sim b \sim 10^{-7}$ cm we obtain a susceptibility $|\chi| \sim 10^{-5}$, i.e., of the same order as in a normal metal.[2)] This is not quite trivial, since the considered system is an insulator. The value of $\chi$ depends specifically on the temperature, vanishing at the exciton-transition point, and on the field, since it is clear that the pairing will be suppressed at a superfluid velocity $v_s \sim \Delta/p_F$ ($\Delta$ is the gap). This corresponds to critical fields $H \sim 10^4$—$10^5$ G at $T=0$. We assume $\Delta \sim T_c \sim 10^2$ °K. The $\chi(H)$ plot is analogous to the "pair-breaking curve" for a superconductor (see e.g., [7]).

For the effects considered in this article to exist, it is necessary to satisfy a number of stringent conditions: equality of the Fermi momenta of the electrons and holes, and isotropy (or congruence) of the Fermi surfaces; a large mean free path, since scattering acts on the state of an excitonic insulator in the same way as magnetic impurities act on a superconductor; the presence of alternation of conducting strings of $n$ and $p$ type, which can be attained, for example, by introducing inert molecules or complexes between the layers; finally, consideration must be given to the role of Umklapp processes, which can secure the exciton in the field of the periodic potential of the lattice, i.e., there will be no free ("superconducting") sliding of an electron pair along the layers. One can hope that in the case of weak pinning of the lattice (or in the case of a large pair coherence radius) this effect will be insignificant.

We note in conclusion that the superstructure noted recently[8,9] at $T < 58$ °K in the salt TTF-TCNQ makes probable, besides other possibilities, an interpretation of the structural transformation in this compound as an excitonic transition of the type considered here.

1)Analogous arguments were formulated by one of us (Fiz. Nizk. Temp., in press[4]).
2)This situation differs from the three-dimensional case considered in[6]. $\chi_{\parallel} = 0$ in layered compounds above the exitonic-transition point.


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