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Temperature dependence of the critical field of the organic superconductor κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br

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We present upper critical magnetic fields data for κ-(BEDTTTF)$_2$Cu[N(CN)$_2$]Br (hereafter k-Br), single crystals with magnetic field applied either perpendicular or parallel to the conducting layers. H-T phase diagram in this compound has been deduced from tunnel diode oscillator-based contactless measurements in pulsed magnetic fields up to 56 T for the inter-plane (H||b) and in-plane (H||ac) field directions. Temperature dependence of the magnetic penetration depth in DC fields is also reported. The temperature dependence of the upper critical magnetic field H_{c2} is not accounted for the Werthamer–Helfand–Hohenberg (WHH) model for in-plane configuration. For the inter-plane orientation, a significant upward curvature is observed as temperature decrease, in the range close to T_c, followed by saturation at lower temperatures. Possibly, this upturn is an indication of flux-line lattice melting.

The temperature-dependence of the upper critical magnetic field $H_{c2}(T)$ in organic superconductors is most likely due to two independent pair-breaking mechanism [1, 2]: (i) close to T_c. Cooper pairing is suppressed by orbital currents that screen the external field, according to the well-known WHH model; (ii) towards lower temperatures, the limiting effect is caused by the Zeeman splitting, i.e., when the Zeeman energy becomes larger than the condensation energy, the Pauli limit, H_p, is reached. This paramagnetic limit, $H_{c2}(T)$, is lower than the orbital one which is related to the slope $dH_{c2}(T)/dT$ close to T_c. Namely, when including Pauli paramagnetism, the upper critical field is reduced relatively to $H_{c2}(T)$:

$$H_{c2}(T) = H^*_{c2}(T)/\sqrt{1+\alpha^2(T)}, \quad (1)$$

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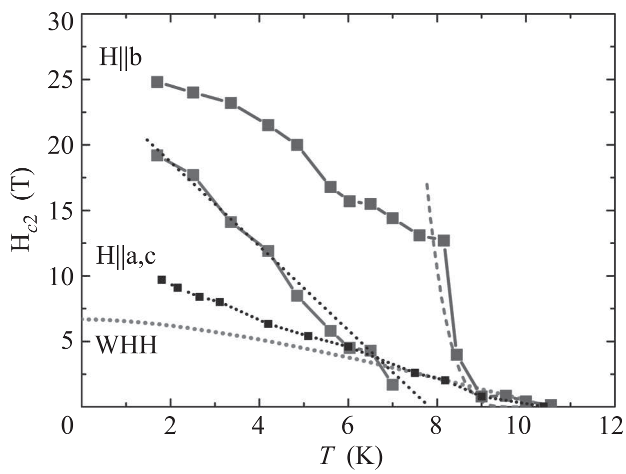

Fig. 1. (Color online) Phase diagram for the k-Br compound with conducting plane oriented parallel (H||ac) and perpendicular (H||b) to the pulsed magnetic fields. Black and blue squares indicate the H_{c2} values inferred from experiments with H||ac and H||b, respectively. Green squares correspond to the melting transition fields $H_m(T)$ data. The red dotted line is the best fit of the WHH model to the data for H||ac. Green dotted line is power low fit close to T_c. [1, 5, 6]. The red dotted line indicate the temperature dependence according to the WHH model neglecting Pauli-limiting

where $\alpha(T) = \sqrt{2}H_{c2}/H_p(0)$ is the Maki parameter [3]. Whether a superconductor is orbitally limited or Pauli limited can be inferred from the α parameter value. Above H_p the Cooper pairs are broken and superconductivity is destroyed. The superconductor made up of weakly-coupled superconducting planes [4] may transform from a three-dimensional system to two-dimensional one [5]. Recently, the change in gradient of H_{c2} vs T in [5] was attributed to dimensional crossover from quasi-two-dimensional (low temperatures) to three dimensional (high temperatures). In this short communication, we report (i) results of the magnetic penetration depth measurements in zero-field for κ-(BEDTTTF)$_2$Cu[N(CN)$_2$]Br single crystals in the temperature range between 1.2 and 15 K and (ii) critical magnetic fields measurements in pulsed fields of up to 56 T in the range 1.2 to 12 K. In both cases, field directions parallel and perpendicular to the conducting ac plane were explored.

Here, we found that below 9 K a definite change in the slope of H_{c2} vs T occurs and H_{c2} begins to follow the power law, $H_{c2}(T) \propto (9.8 - T^*)^4$, with fitted $T^* = 9.8$ K. Notice that this upturn temperature position is almost the same as for $H_m(T)$. Similar upturn was observed for λ-(BETS)$_2$GaCl$_4$ organic superconductor, with T^* as a free parameter. Following [5], we attribute the sharp upturn of Hc2(T) to flux-line lattice melting, and thus characteristic of a two-dimensional superconductor with weakly-coupled layers, because H^* follows the power like dependence $H_{c2} \propto (9.8 - T)^4$ dependence, indeed expected from the Gorter–Casimir two-fluid model [6].

Measurements of the temperature dependence of both upper critical magnetic field and melting transition reveal unusual phase diagram for κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br organic superconductor. The temperature dependence of the upper critical magnetic field $H_{c2}(T)$ shows an upward divergence as the temperature decreases with a sharp upturn at 9 K, and similar upturn for the temperature dependence of melting field $H_m(T)$ (see Fig. 1). We tentatively attribute these two upturns to flux-line lattice melting.

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