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Quantum Transport Phenomena in Molecular Dirac Fermion Systems

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First bulk (multilayer) two-dimensional (2D) zero-gap state with massless Dirac particles was realized in an organic conductor α-$(BEDT\text{-}TTF)_2I_3$ under pressure [1-3]. We have succeeded in detecting the zero-mode Landau level and its spin-split levels in this system probed by inter-layer magnetoresistance [3]. The Shubnikov-de Haas oscillations (SdHO) or the quantum Hall effect (QHE), however, have not been observed yet because Fermi level always locates at the Dirac point. Moreover, the multilayered structure makes control of Fermi level by the field-effect-transistor method much more difficult than in the case of graphene. In this work, we made a breakthrough in the detection of SdHO and QHE in this multilayered massless Dirac fermion system.

According to our investigation of the Hall effect in this system, the carrier density at low temperature is only 10^8 cm^{-2}/sheet [2]. Yet, the carriers are not localized but mobile with high mobilities. Thus, by fixing a crystal on a substrate weakly negatively charged by contact electrification, the effects of hole doping can be detected in the transport. Indeed, we succeeded in detecting the hole doping effects on the magnetoresistance and the Hall effect by fixing a crystal onto a polyethylene naphthalate (PEN) substrate. The detection of SdHO originated from the Dirac particles strongly indicates that the carrier doping was successful. The most impressive phenomenon is the QHE plateaux for ν=4, 6, 10, 14 and 18. Those steps are essence of 2D Dirac fermion systems. Moreover, we reveal that the Coulomb interaction plays an important role to the present Dirac particles.

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