Electromagnetic duality between orbital diamagnetism and quantized conductivity in Dirac electron system

Shigeki Fujiyama

[1]*RIKEN, Hirosawa 2-1, 351-0198 Wako, Japan, e-mail: fujiyama@riken.jp*

α -(BETS)$_2$I$_3$ is a two-dimensional (2D) Dirac electron system with a small mass gap of about 2 meV at ambient pressure. The electrical resistivity is almost independent of temperature for T > 50 K, maintaining a value of h/e^2 Ω per layer above 50 K. Below 30 K, the resistivity slightly increases upon cooling without symmetry breaking. A large orbital diamagnetism originating from the interband effect of the magnetic field is expected in the Dirac electron system not only for 3D systems but also for 2D systems [1]. However, orbital diamagnetism in 2D Dirac fermions has never been directly observed. We succeeded in separating the diamagnetic orbital susceptibility from the paramagnetic spin susceptibility in α-(BETS)$_2$I$_3$ by measuring the anisotropy of the magnetic susceptibility (Fig. (a)) [2]. The observed spin and orbital diamagnetic susceptibilities follow $\chi_{\rm spin} \propto T$ and $\chi_{\rm orb} \propto -1/T$, respectively, in the temperature range above the mass gap, which is consistent with the theory.
Since the electromagnetic response of the Dirac fermion system can be described by quantum electrodynamics (QED), a relativistic quantum theory, the symmetry of the electromagnetic responses originates from Lorentz covariance (space-time symmetry) is expected [3]. We derived the relationship between the magnetic susceptibility $\chi_{\rm orb}$ and the dielectric constant $\sigma(\omega)$ from the theoretical analysis. As a result, we found a scaling relation between the electric conductivity $\sigma_{\rm dc}$ and $-\chi_{\rm orb}T$ in a wide temperature range of T > 50 K, as shown in Fig. (b). This shows that the electromagnetic symmetry is conserved in 2D Dirac electron systems in which electrical conductivity is quantized.

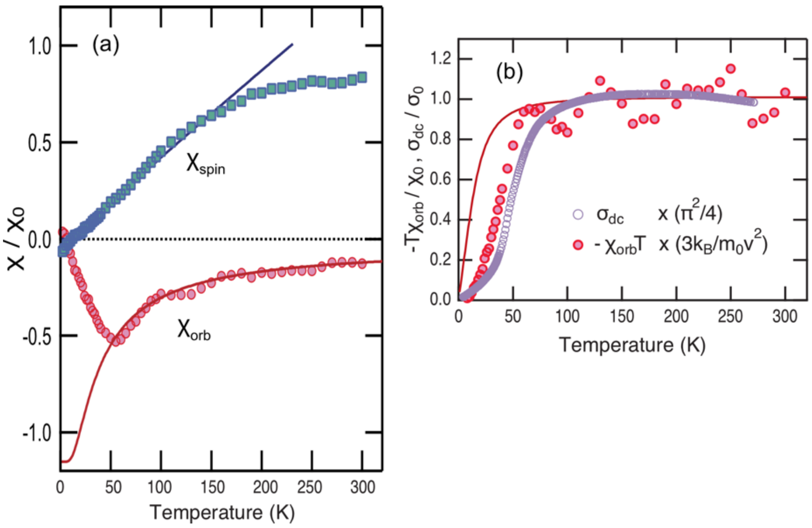

Fig (a) Spin ($\chi_{\rm spin}$) and orbital ($\chi_{\rm orb}$) susceptibilities scaled by $\chi_0 = \mu_0 e^2/2\pi m_0 d$. Solid curves are calculated susceptibilities for Δ = 50 K. (b) Electromagnetic duality of α-(BETS)$_2$I$_3$, where $-\chi_{\rm orb}T$ is scaled by $\sigma_{\rm dc}$ for a wide temperature range. The solid curve is the calculated $-\chi_{\rm orb}T$.

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References

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