Thermal Hall for fractional quantum Hall States of bilayer graphene

Electron-electron interactions in partially filled Landau levels gives rise to strongly correlated topological phase, known as the fractional Quantum Hall (QH) states whose edge structures are not as simple as in integer QH state. Moreover, the edge structures become more intricate for hole-conjugate states like $\nu = 2/3$, 5/3 or 8/3. The frequently studied filling factor, $\nu = 2/3$, was initially proposed to harbour two counter-propagating modes: a downstream $\nu = 1$ and an upstream $\nu = 1/3$, and expected to exhibit electrical conductance, $G_e = 4/3\ e^2/h$. However, the charge equilibration between these modes always led to an observed downstream $\nu = 2/3$ charge mode ($G_e = 2/3e^2/h$) accompanied by an upstream neutral mode. The energy equilibration between the downstream charge mode and upstream neutral mode is expected to exhibit total zero thermal conductance (G_{th}), which has been observed in GaAs/AlGaAs based systems. Here, we have carried out the electrical and thermal conductance of the hole-like fractional QH states ($\nu = 5/3$ and 8/3) along with the particle-like fractional QH states ($\nu = 4/3$ and 7/3) in graphite gated hBN encapsulated bilayer graphene. The measured electrical conductance with precise value of $G_e = 5/3\ e^2/h$ and $8/3\ e^2/h$ for $\nu = 5/3$ and 8/3 strongly suggest the charge equilibration between the counter-propagating edges. The thermal conductance of the particle-like states of $\nu = 4/3$ and 7/3 was found to be consistent with theoretically predicted values of $G_{th} = 2k_0$ and $3k_0$ (where, $k_0 = \frac{\pi^2 k_B^2}{3h} T$). However, the observed value of thermal conductance of hole-like states $\nu = 5/3$ and 8/3 with $G_{th} = 3k_0$ and $4k_0$ is strikingly different from earlier observation with values k_0 and $2k_0$ in GaAs/AlGaAs with full equilibration of energy. Our results, hitherto not known, reveal the complex nature of equilibration of counter-propagating edges for hole-like fractional QH states in graphene.