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Wiedemann-Franz Law Violation in Graphene and Quark Matter: A Relativistic Fluid Perspective

The Wiedemann-Franz law, a hallmark of non-relativistic electron transport, relates the thermal and electrical conductivities through a constant Lorenz ratio. This ratio remains fixed in conventional metals, consistent with Fermi gas and Fermi liquid theory. Interestingly, quarks or hadrons in the matter produced in RHIC or LHC experiments don't follow this law. This high-energy nuclear physics-based many-body system (QCD phase diagram) is expected in the temperature and (baryon) chemical potential within the order of MeV-GeV scales. In contrast, a condensed matter physics-based many-body system is expected within meV-eV temperature scales and Fermi energy(chemical potential). Though metals, having Fermi energy from 2eV to 10 eV, follow the WF law but graphene can reach the WF law violation domain by lowering its Fermi energy via the doping reduction technique. By drawing a parallel between graphene's Dirac fluid and hot quark matter, we aim to explore the transport behavior that emerges in strongly interacting, relativistic fluids across vastly different energy scales. We employed the Boltzmann transport theory to determine the thermal and electrical conductivities in graphene and ultra-relativistic quark matter. We observed a striking violation of the Wiedemann-Franz law in both systems. The present work highlights the universal nature of transport phenomena in Dirac fluid and relativistic fluids, from the milli-electron volt (meV) scale in graphene to the mega-electron volt (MeV) scale in quark matter, providing insight into the fundamental physics governing both condensed matter and high-energy systems.

Category

Theory

Collaboration (if applicable)

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