Radiative heat transfer in 2D Dirac materials

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Abstract — We compute the radiative heat transfer between two sheets of 2D Dirac materials, including topological Chern insulators and graphene, within the local optics approximation. We derive both numerically and analytically the short-distance asymptotics of the near-field heat transfer in these systems, and show that it scales as the inverse of the distance between the two sheets. We discuss the limitations to the validity of this scaling law imposed by spatial dispersion in 2D Dirac materials.

Two-dimensional Dirac materials constitute a class of materials that carry electrons governed by the Dirac equation. Since the discovery of the first Dirac material graphene, the past ten years have seen another expanding family of such materials now including topological Chern insulators, transition-metal dichalcogenides (TDMC), as well as silicene and germanene. Because of their atomic thickness and unusual electronic properties compared to conventional materials, optical transport properties of Dirac materials have received particular attention recently generating prospects for using them in graphene photonics, graphene plasmonics, and TDMC-based valleytronics.

The interesting magneto-optical properties of 2D Dirac materials strongly modify fluctuation-induced interactions between them, including momentum transfer (Casimir forces) and energy transfer (radiative heat exchange). Remarkably, a strong magnetic field in the out-of-plane orientation between two graphene sheets was shown to result in a quantized Casimir force \cite{1}, and a similar effect between Chern insulators without an external magnetic field has also been predicted \cite{2}. For the case of radiative heat transfer, previous works have focused on grapheme systems in the metallic regime, when the Fermi level lies in one of the bands, and the heat transfer is dominated by the effects of surface plasmon polarities corresponding to the optical Drude response near the Fermi level \cite{3, 4, 5}. Thermally excited graphene plasmons can substantially increase radiative heat transfer at short separations. Lifting of the degenerate Dirac point by time-reversal symmetry (as in the case of Chern insulators) or by spatial inversion symmetry (as in the case of 2D TDMC) results in a Dirac insulator with a band gap. When the chemical potential lies within the band gap, the plasmonic contribution to the radiative heat transfer is exponentially suppressed and the heat transfer is mainly due to interband optical transitions.

The short-distance asymptotics of dispersion interactions depends on the dimensionality and optical properties of the involved bodies, and has been studied in the past for selected materials. In the case of near-field heat transfer in 3D systems, the heat exchange scales as the inverse of the squared distance between the plates, when their optical properties are treated within the local optics approximation (i.e. no spatial dispersion included). At very short separations, this scaling law breaks down due to the spatial dispersion effects, and heat transfer saturates. The precise distance when this cross-over to saturation occurs depends on the kind of materials, eg. metals \cite{6} or dielectrics \cite{7}.

Here, we investigate the radiative heat transfer between two-dimensional Dirac materials within the local approximation for the optical response. In particular, we study the asymptotic short-distance behavior of near-field heat transfer in these systems, including topological Chern insulators and graphene, and show a scaling law at short separations that goes as the inverse first power of distance \cite{8}. We also argue that this scaling law is valid for any two-dimensional material, as long as the local approximation remains valid. As in the case of 3D metals and dielectrics mentioned above, we expect this scaling law to break down at very short separations. Unfortunately, to date there is no widely accepted treatment in the literature of nonlocal effects on the optical response of 2D Dirac materials, which prevents us from assessing the precise region of validity of the local approximation used in this work.
REFERENCES