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Transport properties in magnetized compact stars

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Nowadays strong magnetic field has been observed or expected in compact stars or during relativistic heavy-ion collisions. In particular, magnetars may have a huge magnetic field of $O(10^{15} \text{ G})$ at the surface. We here consider the transport properties of Dirac particles in the presence of a strong magnetic field. As a phenomenological implication, the heat conductivity is interesting and important in the context of the thermal evolution of magnetars: The heat conductivity is, in general, a tensor in the coordinate space, κ_{ij} ($i, j = x, y, z$); the off-diagonal components represent the thermal Hall conductivity.

First, we discuss the electron contribution in the crust of magnetars, since the main mechanism of thermal transport is responsible for conducting electrons. The diagonal components give the thermal currents proportional to the gradient of temperature. It comes from some dissipative effects for electron propagation and has a classical analogy to the Drude-Zener formula. On the other hand, the off-diagonal components consist of two parts $\kappa_{ij} = \kappa_{ij}^I + \kappa_{ij}^{II}$ ($i \neq j$), where the first term represents the dissipative contribution similar to the diagonal components and has been studied by many authors [1]. However, there is a little study about the second term, which is a genuine quantum effect and gives a non-dissipative contribution. It comes from the field-dependent level density and has no classical analogy [2]: the Landau levels become essential in the strong magnetic field and the density of states (DOS) is a field-dependent quantity, while DOS is not field dependent in the classical limit. Sometimes κ_{ij}^{II} has been missed in the literature. We elucidate its contribution by way of the Kubo formula and estimate its importance.

Next, we discuss the anomalous thermal Hall effect in quark matter, which may develop in the core of compact stars. Recently we have shown a possibility of the anomalous Hall effect in dense QCD matter by the use of the Kubo formula [3], where inhomogeneous chiral phase (DCDW phase) is realized [4]. The important consequence is that the Hall conductivity κ_{ij} becomes nonvanishing even in the absence of the magnetic field. It has a geometrical origin and modifies the Maxwell equation as in the Weyl semimetal [5]: the energy spectrum exhibits asymmetry with respect to the zero energy to produce a kind of "magnetization" in the DCDW phase, and the Hall current flows in the direction perpendicular to the magnetization. Since thermal conductivity is closely related to conductivity κ_{ij} , we can expect the anomalous thermal Hall effect there as well [6]. It then should give another contribution to the thermal conductivity independent of the magnetic field. We discuss the interplay of these terms in the non-dissipative contribution κ_{ij}^{II} .

Finally, we briefly discuss some implications of the non-dissipative thermal Hall conductivity κ_{ij}^{II} , in the context of thermal evolution of magnetars.

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