Interference and interaction of charge carriers in graphene

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Abstract

Electron transport at low temperatures in two-dimensional electron systems is governed by two quantum corrections to the conductivity: weak localisation and electron-electron interaction in the presence of disorder. We present the first experimental observation of these quantum corrections in graphene, a single layer of carbon atoms, over a temperature range 0.02 - 200 K. Due to the peculiar properties of graphene, weak localisation is sensitive not only to inelastic, phase-breaking scattering events, but also to elastic scattering mechanisms. The latter includes scattering within and between the two valleys (intra- and inter-valley scattering, respectively). These specifics make it possible, for example, to observe a transition from weak localisation to antilocalisation. Our work reveals a number of surprising features. First of all the transition occurs not only as the carrier density is varied, but also as the temperature is tuned. The latter has never been observed in any other system studied before. Second, due to weak electron-phonon interaction in graphene, quantum interference of electrons survives at very high temperatures, up to 200 K. For comparison, in other two-dimensional (2D) systems the weak localisation effect is only seen below 50 K.

The electron-electron interaction correction is also affected by elastic scattering. In a two-valley system, there are two temperature regimes of the interaction correction that depend on the strength of inter-valley scattering. In both regimes the correction has its own expression. We show that because of the intra-valley scattering, a third regime is possible in graphene, where the expression for the correction takes a new form. The study of weak localisation demonstrates that the third regime is realised in our experiments. We use the new expression to determine the Fermi-liquid parameter, which turns out to be smaller than in other 2D systems due to the chirality of charge carriers.

At very low temperatures (below 100 mK) we observe a saturation of the electron dephasing length. We study different mechanisms that could be responsible for the saturation and discuss in detail two of them – spin-orbit interaction and electron scattering off vacancies. We determine the spin coherence length from studies of weak localisation and the temperature dependence of the conductivity and found good agreement between the two types of experiments. We also show the way to

tune the spin coherence length by an order of magnitude by controlling the level of disorder. However, experiment shows contradictions with theory both in values of the spin coherence length and the type of spin relaxation. We speculate about another spin-related mechanism, spin flip by vacancies.

We also present electron transport in graphene irradiated by gallium ions. Depending on the dosage of irradiation the behavior of electrons changes. Namely, electron localisation can be tuned from weak to strong. At low dosages we observe the weak localisation regime, where the mentioned quantum corrections to the conductivity dominate at low temperatures. We found the electron scattering between the valleys to be enhanced, attributing it to atomically sharp defects (kicked out carbon atoms) produced by ion irradiation. We also speculate that gallium ions can be embedded in the substrate or trapped between silica and graphene. We draw this conclusion after investigation of the spin-orbit interaction in irradiated samples. At high dosages electrons become strongly localised and their transport occurs via variable-range hopping.

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Contents