Sagnac and Mashhoon effects in graphene

Sergei G. Sharapov

Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

The Sagnac effect refers to the phase shift between two coherent waves, such as light, traveling in opposite directions within an interferometer mounted on a rotating disk. The magnitude of the phase shift is directly proportional to the area enclosed by the light rays, the frequency of the light, and the angular velocity of the interferometer's rotation. Given that material particles also exhibit wave-like properties, the Sagnac effect has been experimentally observed in free electrons in vacuum, neutrons, and even atoms. Moreover, when the Sagnac effect is realized on electrons, the resulting phase shift in the interference pattern is roughly a million times larger than that for light. This prompted a theoretical question: how would the Sagnac effect manifest in solid-state interferometers using free electrons in monolayer graphene? Graphene is known for its zero effective carrier mass and linear electron dispersion, properties that closely resemble those of light.

We investigate the Sagnac and Mashhoon effects in graphene, taking into account both the pseudospin and intrinsic spin of electrons, within a simplified model of a rotating nanotube or infinitesimally narrow ring. Based on considerations of the relativistic phase of the wave function and employing the effective Larmor theorem, we demonstrate that the Sagnac fringe shift retains a form analogous to that for free electrons, governed by the electron's vacuum mass. As a result, the effect in graphene remains approximately a million times stronger than in light-based interferometers. In the case of a narrow ring, an additional π-phase shift arises due to the Berry phase associated with the honeycomb graphene lattice. The Mashhoon fringe shift, which characterizes the dynamics of intrinsic spin, retains its conventional form in graphene, with its dependence on the Fermi velocity. Our analysis highlights both the similarities and differences between spin and pseudospin degrees of freedom in graphene.

References

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