THE UNIVERSITY OF HONG KONG

DEPARTMENT OF PHYSICS
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Quantum Kinetic Theory of the Orbital Magnetic Moment of Bloch Electrons

Prof. Dimi CULCER

University of New South Wales (UNSW Sydney)

Abstract:

The orbital magnetic moment (OMM) of Bloch electrons has been known for a long time for over half a century, and a well-established semiclassical description of it exists. It has come under renewed scrutiny recently as part of a general effort to understand angular momentum dynamics in systems in which spin-orbit interactions are absent or negligible - including graphene, transition metal dichalcogenides, and topological antiferromagnets. Yet despite intense interest in the OMM its fundamental properties are poorly understood. At present there is no quantum mechanical theory of the OMM, part of the problem being that dealing with the position operator between Bloch states is non-trivial. This is a significant gap: without knowing when the OMM is conserved, for example, we cannot discuss meaningfully orbital currents and the orbital Hall effect.

I will present two recent results from our group. The first is related to the orbital Hall effect [1]. The theory of the orbital Hall effect (OHE), a transverse flow of orbital angular momentum in response to an electric field, has concentrated overwhelmingly on intrinsic mechanisms. We have determined the full OHE in the presence of short-range disorder using 2D massive Dirac fermions as a prototype. We find that, in doped systems, extrinsic effects associated with the Fermi surface (skew scattering and side jump) provide $\approx$95% of the OHE. This suggests that, at experimentally relevant transport densities, the OHE is primarily extrinsic.

In the second part I will introduce a quantum mechanical theory of the OMM due to intrinsic mechanisms [2]. The theory is based on the density matrix and quantum Liouville equation. I will show that the OMM is in general not conserved in an electric field. The force moment produces a torque on the OMM, which is determined by the quantum geometric tensor and the group velocities of Bloch bands. The torque vanishes in two-band systems with particle-hole symmetry, but is nonzero otherwise. For tilted massive Dirac fermions the torque is determined by the magnitude and direction of the tilt.

[1] Hong Liu and D. Culcer, arXiv:2308.14878.
[2] R. Burgos Atencia and D. Culcer, arXiv:2311.12108.

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Room 522, 5/F, Chong Yuet Ming Physics Building, The University of Hong Kong

Department of Physics, Chong Yuet Ming Physics Building, The University of Hong Kong
Phone: 28592360 Fax: 25599152. *Anyone interested is welcome to attend.*