Electronic and magnetic properties

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The description of the solid-state tackles the challenges of the third infinity, the infinite number of particles. Zillions of electrons and atomic nuclei interact through the Coulomb interaction, leading to an inexhaustible wealth of crystalline and collective phases (e.g. ferromagnetism, skyrmions lattice) of matter. The interplay of the properties of particles and quasiparticles with collective excitations leads to a rich spectrum of phenomena. It is clear that solids can only be understood within the framework of quantum theory combined with statistical physics. This does not exclude that some properties of condensed matter are qualitatively or even quantitatively describable with classical mechanics or statistics.

Starting point of any description of the electronic and magnetic properties of solids is the Hamiltonian operator describing the quantum nature of the electrons and atoms. From this starting point we move quickly over the single particle picture in which we can discuss the band structure of the crystalline solid. Two powerful theories are introduced, the density functional theory for the description of ground state properties, where the quantum mechanical Hamiltonian that lives in an N-dimensional Hilbert space is mapped to single particle description at the expense of a non-linear problem to be solved self-consistently; and the *GW* approximation of the electron self-energy which allows the description of the excited state. The consequences of these theories are discussed at some examples.

The spin-orbit interaction or spin-orbit coupling which couples electron's momentum and spin is a small one and is frequently neglected in the discussion, but bears fascinating realizations and ramifications in magnetic solids and solids facing. Examples include the Rashba-effect and Dresselhaus effect, topological and Chern insulator, as well as Weyl semimetals, orbital magnetic moment, magnetocrystalline anisotropy, spin-relaxation phenomena (Elliot-Yafet, Dyakonov-Perel), magnetic interaction as the Dzyaloshinskii-Moriya interaction, magneto-transport phenomena like, the anisotropic (tunneling) magnetoresistance, spin-orbit torque, the Hall quartet, anomalous-, spin-, quantum spin-, quantum anomalous Hall effect, etc.). Thus, we will introduce the spin-orbit interaction and derive models, which describe some of the effects, which we will discuss in details.

After the introduction of Ohm’s law, the conductivity tensor with the off-diagonal transversal transport coefficients, I discuss the Hall-quartet on the level of linear response theory using the Kubo-formalism introduced on the level of the Berryology.

There are many good books on electronic properties and manuscripts that cover parts of the lecture.

[1] Ashcroft/Mermin, *Solid State Physics*, Holt, Rinehart, Wilson ISBN 0-03-049346-3
[2] C. Kittel, *Quantum Theory of Solids,* John Wiley & Sons, ISBN 0-471-62412-8
[3] T. Matsubara, *The Structure and Properties of Matter*, Springer series in Solid-State Sciences 28 Springer Verlag: Berlin, Heidelberg, New-York ISBN 0-387-11098-4
[4] Zutic I, Fabian J and Das Sarma S, Rev. Mod. Phys. **76**, 323–410 (2004).
[5] A. Bohm, A. Mostafazadeh, H. Koizumi, Q. Niu, and J. Zwanziger, *The Geometric Phase in Quantum Systems*, Springer-Verlag Berlin Heidelberg (2003).
[6] B. A. Bernevig and T. L. Hughes, *Topological Insulators and Topological Superconductors*, Princeton University Press (2013).
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