TUT 3: Spin-Orbit Coupling

The last decade of research in solid state physics has been marked by the realisation that the spin-orbit interaction can have a very important impact on the electronic properties of materials as diverse as semiconductors, magnets, and superconductors. The peculiar role of spin-orbit coupling is at the basis of many exotic electronic states in condensed matter, such as the spin-Hall insulator, topologically protected states, or topological superconductivity. It is also at the basis of booming research into possible novel applications in the realm of (spin-)electronics. Therefore, the thorough understanding of spin-orbit coupling and its possible effects should be an essential ingredient of the intellectual luggage of any student of solid state physics. It is the purpose of this tutorial to review some of the main ideas at hand.

Organizer: Kees van der Beek (Paris), Chair of the EPS Condensed Matter Division

Time: Sunday 16:00–18:15 Location: H 1012

Tutorial TUT 3.1 Sun 16:00 H 1012

Role of spin in the structure of matter and spin-related phenomena — •Michel I. Dyakonov — Laboratoire Charles Coulomb, Université Montpellier, France

While it can seem that the existence of the internal angular momentum - spin and the associated magnetic moment of the elementary constituents of matter (proton, neutron, electron) is a minor detail compared to their strong and electromagnetic interactions, in reality this property defines the whole structure of our world. The reason for this is that these particles are fermions, which obey the Pauli principle. This defines the fundamental properties of atoms, molecules, and solids.

A brief review will be presented of not so fundamental, but still quite interesting, spin-related phenomena, which have been studied for a long time and especially intensively in recent years:

Optical spin effects in atomic and solid state physics

- Optical spin orientation and detection
- Hanle effect
- Hyperfine interaction and nuclear magnetic fields

Electrical spin-related effects

- Spin resonance
- Anomalous Hall effect
- Spin currents
- Spin Hall Effect
- Spin Hall magnetoresistance
- Swapping spin currents
- Perspectives

Tutorial TUT 3.2 Sun 16:45 H 1012

From the Spin Hall Effect to the Quantum Spin Hall Effect — •Hartmut Buhmann — Physikalisches Institut, Universität Würzburg, Würzburg, Germany

Each Hall effect appears to show up with a quantum version where the related conductance is quantized. In solid state materials spin orbit interaction provides a source which leads to a distinct charge separation. In this case the charges deflected to the sides perpendicular to a current flow are characterized by an opposite spin polarization referred to a spin Hall effect. In narrow gap materials spin orbit interaction can lead to a bulk band inversion. In those materials an opposite spin current is observed at the edge of the sample. Due to a quantized charge current this effect is call the quantum spin Hall effect. In this lecture the consequences of a strong spin orbit interaction in semiconductor materials are discussed. Since the spin orbit effect is strongest in narrow gap materials containing heavy elements I will focus here on transport experiments and HgTe quantum well systems which can be viewed as a prototype material for the realization of the spin Hall [1] and quantum spin Hall effect [2].

[1] C. Brüne et al., Nature Physics, 8, 485 (2012).
[2] König et al., Science 318, 766 (2007).

Tutorial TUT 3.3 Sun 17:30 H 1012

Spin Orbit Coupling in Doped Mott Insulators — •Alessandra Lanzara — Physics Department, University of California, Berkeley — Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley

Two types of interactions commonly drive new emergent phenomena beyond textbook band theory in quantum materials: electron correlation and spin orbit coupling. The first, born from the observation of Mott that strong electron correlation can drive a system, otherwise metallic, on the verge of being an insulator, has excited the condensed matter community over the past several decades and lies at the core of many unsolved phenomena, such as unconventional superconductivity. The second, derives from the relativistic correction to the hydrogen-like atom, and has been vastly explored in the previous decades in the context of Rashba effect. Recently, the realization that strong spin orbit coupling can induce dramatic effect on the band structure of weakly interacting systems driving new phases of matter such as the topological band insulators has sparked huge interest in this emerging field. The real frontier today is to understand whether strongly interacting systems can exhibit any type of intrinsic topological order, distinct from band topology in insulators and what consequences this might have.

In this talk I will present experimental results for a variety of materials spanning the entire range of interaction, from strong correlation (Mott insulators), to strong spin orbit coupling (topological insulators) and intermediate interaction regime (spin orbit coupled Mott insulators). I will present intriguing results on the interplay between these two interactions. The future of the field is discussed.