Magnetism of atoms an ions

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In order to understand magnetism in a real material, we need address to the quantum mechanical origin of the magnetic moment on the atomic scale. This introductory lecture will serve this purpose and combines aspects of the non-relativistic Schrödinger equation of electrons in a Coulomb potential and its relativistic corrections, i.e. the spin-orbit interaction. Further, it will include some aspects of the Dirac equation to illustrate the origin of the spin and discuss the Stern-Gerlach experiment. The lecture will thus summarize the quantum mechanics of orbital and spin momenta, their coupling and the rules that govern the occupation of single electron states in isolated atoms or ions in electronic shells. The atomic electron-electron interaction will be discussed leading to Hund's rules that give the ground state configuration of open shells. This will be applied to transition metal and rare earth atoms and ions. Also the action of an external magnetic field on the atomic states, i.e. the extraordinary Zeeman effect, will be discussed and its consequences for the occupation of the states in thermal equilibrium. The theory will be compared with experimental data on the magnetization of paramagnetic substances.

As the magnetic moment is a results of angular momenta, its dynamics is not trivial. We will deduce some of the basic equations of precession of the magnetic moment when exposed to a static magnetic field plus a radio frequency excitation, i.e. magnetic resonance.

When single magnetic atoms or ions are placed in a crystal lattice (or in an organic molecule), the electrons feel the electrostatic potential of the neighboring atoms or ions breaking rotation symmetry. We will briefly review the physics of the crystal or ligand field, which splits the ground state multiplet even at zero magnetic field. In transition metal atoms and ions, the crystal field often completely quenches the orbital magnetic moment, while in rare earth atoms and ions, the open 4f shell is much more localized such that the Coulomb interaction to nearest neighbors is weaker than the spin-orbit interaction of the 4f electrons protecting the orbital momentum from quenching.

Finally, we will discuss the consequences of zero field splitting on the paramagnetic magnetization curves and magnetic resonance experiments.

The lecture requires some prior knowledge on basic quantum mechanics and simple thermodynamics. As an introduction to this lecture, the following textbooks are an excellent choice:

- J. M. D. Coey, Magnetism and Magnetic Materials, Cambridge University Press (2010), Chapters 3, 4 and 9

- S. Blundell, Magnetism in Condensed Matter, Oxford University Press (2001), Chapters 1,2 and 3
- C. Kittel, Introduction to Solid State Physics, John Whiley and Sons (2005), Chapter 11