An introduction to Magnetism in three parts

Wulf Wulfhekel, Karlsruhe Institute of Technology, Germany

Introduction

The lecture on magnetism in three parts serves an an introduction to the origin of the magnetic moment in matter, the relevant magnetic phenomena and magnetic energies involved. It is aimed at bringing all students to a common and fundamental level and serves to lay the foundation for the more specialized lectures on aspects of magnetism.

Part I: The magnetic moment of the atom and crystal fields

Part I will begin with a short review of the Maxwell equations, the definition of the magnetic field H, the magnetic flux density B, the Magnetization M and their units in different systems. The source of magnetic moments in matter, i.e. circular charge currents and spin angular momentum, will be discussed. The magnetic moment of atoms and ions will be describes quantum mechanically based on Hund´s rules and the Landé g-factor. Also problems is this perturbative approach will be mentioned related to the spin-orbit interaction and Berry phase phenomena in current density fields.
When single atoms are placed in an environment, their rotational symmetry is broken by the crystal field of their neighbours. As a consequence, part of the orbital magnetic moment is quenched. Also depending on the size of the crystal field splitting, the ground state can deviate from that predicted by Hund`s rule. We will discuss both 3d and 4f magnetism and their differences.
Finally, we will discuss the thermodynamics of non-interacting magnetic moments in an external field and discuss simple models of the interaction of magnetic moments via quantum mechanical exchange. In the last part, we also discuss the technical use of the discussed phenomena.

Part II: The continuum model of magnetism

Taking a step back from the microscopic view, we will describe the densely packed discrete quantum mechanical magnetic moments as a continuum of a classical magnetization field of constant absolute value. This continuum model has been very successful in the description of ferromagnets even down to the nm scale. This is due to the fact that with size, the quantum mechanical nature is quickly lost in favour of a classical behaviour. We will discuss the relevant contributions to the total energy, i.e. the Zeeman energy of an external field, the magnetic anisotropy energy, the exchange energy and the dipolar energy, i.e. the Zeeman energy of the magnetic structure in a field that it creates itself. While the first terms are all local in nature, the last term is non local as it links every moment with every moment by dipolar interactions. The treatment of the first terms is rather straight forward; the latter term brings complexity to the continuum model. We will discuss the special case that all magnetic moments stay aligned, i.e. the single domain limit. We will investigate the magnetostatic behaviour of single domain particles including all terms in the energy.

Part III: Thermal stability and hysteresis in single domain particles

In the last part, we will discuss the phenomenon of magnetic hysteresis, i.e. the fact that a ferromagnetic state has a memory. We will explain for ideal systems, how the coercivity and the remanence arises and discuss the thermal stability of the magnetization. We will show in how far this idealized Néel-Brown behaviour is realized in real samples and what effects lead to a deviation from the theory. This last part of the lecture has high relevance for magnetic information storage and we will illustrate, how this topic might develop in the near future. We will end with a short overview over dynamic phenomena in magnetic samples, such as the consequences of the magnetization being related to angular momentum. This causes precessional motion of the magnetic moments when exposed to an effective field.

References

There are many good textbook that focus on magnetism. Particularly suited (reflecting my personal taste) are:

[1] Soshin Chikazumi, Physics of Ferromagnetism, Oxford University Press, 2nd edition, 672 pages (2009).
- Very comprehensive and comprehensible book that has recently been updated in the second edition. -

[2] Stephen J. Blundell, Magnetism in Condensed Matter, Oxford University Press, 256 pages (2001).
- The most comprehensible and compact book on magnetism.-

[3] J.M.D. Coey, Magnetism and Magnetic Materials, Cambridge University Press, 628 pages (2010).
- A very comprehensive and clearly written book with a lot of information also on magnetic materials. It is also available as e-book, eventually for free from your home university library.-