Spin excitations in magnetic structures of different dimensions

W. Wulfhekel, Universität Karlsruhe (TH), Wolfgang Gaede Str. 1, 76131 Karlsruhe, Germany
e-mail: wulf.wulfhekel@pi.uni-karlsruhe.de

Magnetism is an effect, that is intimately linked to the spin of the electron. While paramagnetic and diamagnetic substances show no spontaneous magnetic order, ferromagnets, antiferromagnets and ferrimagnets show an ordered configuration of magnetic moments below the critical temperature [1]. The nature of the magnetic ground state is related to the exchange energy of the involved electrons as well as the magnetic anisotropy caused by the spin-orbit interaction and the classical magnetic dipole interaction between the magnetic atoms. Intensive research has lead to a deep understanding of the magnetic ground state, the detailed spin configuration and the physical properties of the material in the ground state [2].

For modern applications, e.g. the storage of non-volatile magnetic information, the fact is used that there are several degenerate ground states (and metastable states), i.e. states of identical energy but different orientation of the magnetic moment. This can be the two states of a magnetic bit on a perpendicular recording media either pointing up or down. Besides the ground state properties, also properties of the excitation spectrum of magnetic structures are of importance for the function of a device. In every working device, the device has to fulfill a function, i.e. its state has to be changed in time. This can be the writing of magnetic information into a magnetic bit, e.g. the reversal of the bit from up to down, the sensing of a magnetic field in a read head of a hard disk or the switching of a spin transistor in a spintronic device. In this process, the devices has to be excited from its ground state to overcome the energetic barrier between different magnetic states and energy is consumed by the device. Thus, the excitations play an as important role as the ground state properties for the function of a device. They have, however, not been studied as intensively as the ground state properties and the knowledge of these excitations will be of mayor importance for future development of high speed devices.

Further, all devices will be operated at finite temperature and issues of magnetization stability come of importance [3]. For example, the magnetic bit on a hard disk has to be thermally stable over long periods of time to prevent the loss of data. Also thermal switches of magnetization bits are intimately linked to the spectrum of magnetic excitations.

The classical approach to describe magnetic excitations is to use the Heisenberg model of spins that interact with their nearest neighbors via the exchange interaction [4]. Treating the spin as a classical vector, the excitations can be described as spin waves traveling through a magnetic crystal [1,5].
The spin wave spectrum will be discussed in all detail for ferromagnets of different dimensions (3d, 2d, 1d and 0d) and the role of the exchange, the anisotropy and the dipolar energy will be discussed. While the exchange interaction is the dominant interaction for short wave length spin waves leading to a parabolic dispersion, the anisotropy and the dipolar energies dominate the low energy part of the spectrum and determine the spin wave gap and the group velocities near the center of the Brillouin zone. The spin wave spectrum of ferromagnets will be compared with that of antiferromagnets, that show a liner dispersion much like sound waves. Further, the thermodynamics of spin waves in different dimensions will be introduced and predictions on magnetic ordering will be compared with experimental results. For structures on the nanometer scale, finite size effects as the reduction of the ordering temperature with reduction of the structures size and dimension have been observed [6].

As the classical description of of localized moments does not cover the full physics in metallic itinerant ferro- and antiferromagnets like Fe, Co, Ni or Cr, a quantum description of excitations in the form of magnons and Stoner excitations is needed [7]. This description is based on a direct exchange interaction of the delocalized electrons in the metals and leads to significant modifications of the excitation spectrum and excitation lifetimes [8]. As magnons and Stoner excitations (bound electron-hole pairs of opposite spin) have the same quantum numbers, they tend to couple in regions of the dispersion where they coexist leading to short life times of magnons and efficient damping.

Finally, the basic experimental methods to investigate magnetic excitation are introduced. They range from the interaction of photons with the magnetization (ferromagnetic resonance, Brillouin light scattering) to the interaction of neutrons and electrons with the magnetization (Neutron scattering, Spin-polarized electron energy loss spectroscopy). Several examples of experimental results obtained with the different techniques will be discussed as well as the advantages and disadvantages of the different approaches regarding their sensitivity, energy resolution and range of momentum transfer [1].

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