# Chirality in EELS: Progress and Applications

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Theoretically, everything that can be done in a synchrotron is also feasible in an electron microscope. In practice, however, electron and photon probes behave quite differently. In this respect, the EMCD technique (energy loss magnetic chiral dichroism) in the electron microscope [1,2] - the equivalent of the synchrotron based XMCD, a standard technique for the study of atom specific magnetism - has the intrinsic advantage of high spatial resolution. But there are many obstacles in taking a dichroic energy loss spectrum that do not exist for synchrotron radiation. The main difficulty with EMCD is the notoriously low signal intensity, asking for exposure times of the order of minutes, and the very particular scattering conditions necessary to observe a chiral dichroic signal. Nevertheless, much progress was made in the last years. The signal strength could be considerably increased, and some innovations such as using a convergent beam have been introduced. EMCD has evolved into several techniques, now utilising either energy filtering, spectroscopy, TEM or STEM conditions.

After a synopsis of the present situation in EMCD, we highlight recent results such as nanometric resolution [3], the applicability of XMCD sum rules [4,5], and a new image simulation software [6]. Furthermore we discuss potential applications of this technique like the investigation of magnetism of individual magnetic nanoparticles. Such nanoparticles, which can be made e.g. of $Fe_3O_4$, are due to their magnetic properties interesting for a variety of applications like magnetic markers in biotechnology or as magnetic ink for printable magnetic bar codes. In Fig. 1 an example of recently obtained EELS spectra of an 8 nm sized magnetite particle showing a dichroic signal at the Fe edge is given.

The observation that chiral electronic transitions break certain mirror symmetries in energy spectroscopic diffraction (ESD) led to the prediction that this chirality pertains in the energy filtered HR image [7], thus opening a road to mapping electron spins of individual atomic columns under HR-TEM conditions - see Fig. 2. We discuss the necessary conditions to do so and present a feasibility experiment on the SuperSTEM facility.

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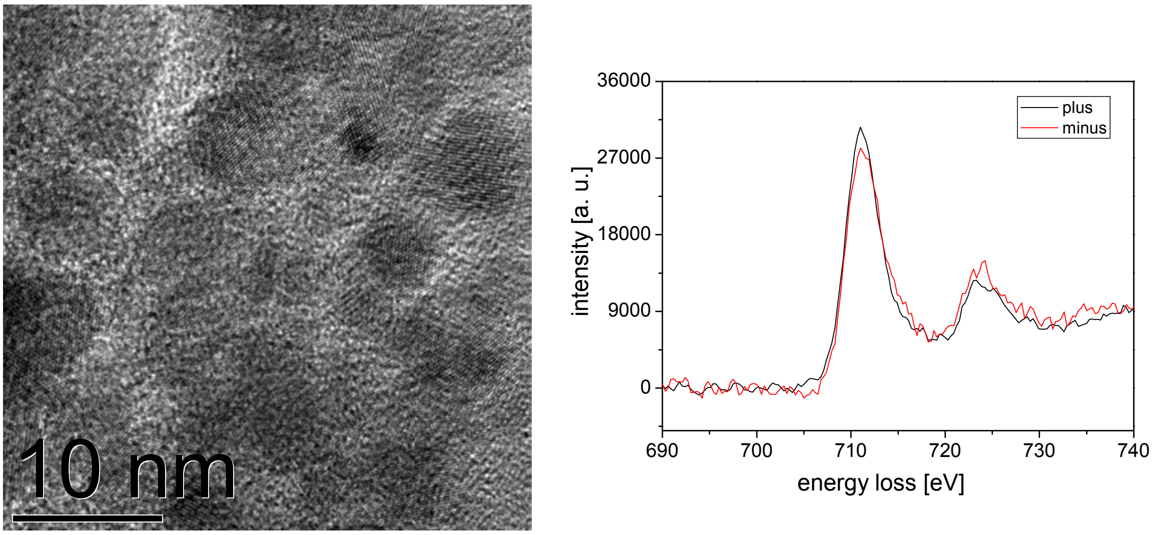

**Figure 1.** TEM image of magnetite particles with a mean diameter of (7.9±2.9) nm deposited on a carbon coated Cu grid (left) and experimentally obtained EELS spectra of the Fe $L_{2,3}$ edge (right). The spectra have been measured at an individual particle using the convergent beam diffraction geometry [3]. The difference reveals the dichroic signal of the investigated magnetite particle.

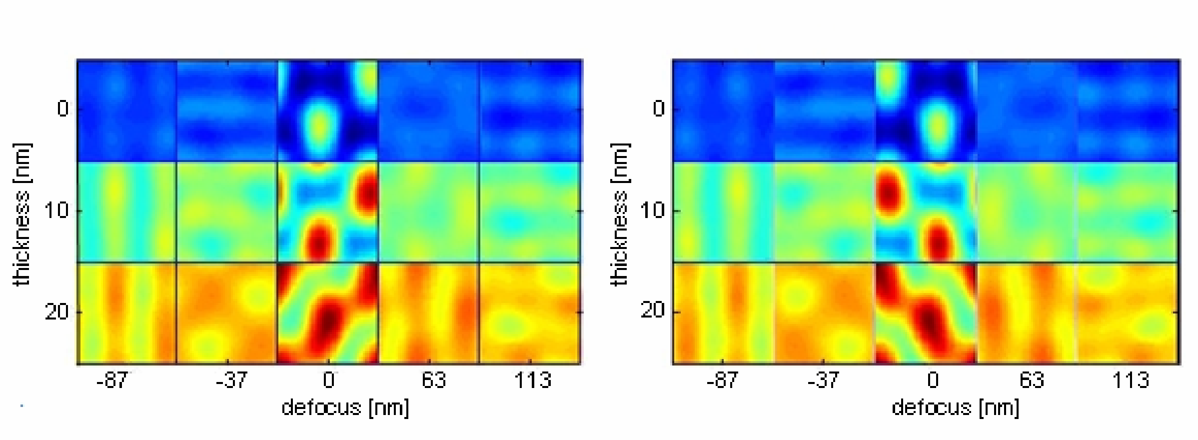

**Figure 2**. HR-EMCD image simulation of the Fe $L_3$ signal for an elementary cell of bcc Fe, [001] zone axis, for complete orbital magnetisation in positive (left) and negative (right) zone axis direction, for different defocus and thickness. The symmetry broken by the magnetic field is best visible at Scherzer defocus for d=10 nm @ 200 kV.

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