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EMCD - Magnetic Chiral Dichroism in the Electron Microscope

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The discovery of energy loss magnetic chiral dichroism (EMCD) has created a new approach to element specific magnetic measurements with highest spatial resolution [1]. EMCD, which is detected in the fine structure of energy loss spectra in a transmission electron microscope (TEM) probes the same electronic transitions as its well established X-ray counterpart, the X-ray magnetic circular dichroism (XMCD). The geometry is sketched in Fig.1.

The extremely high spatial resolution of modern TEMs makes EMCD interesting for spintronic applications. Due to the differences between electron and photon probes some experimental challenges have to be dealt with when acquiring a dichroic energy loss spectrum. For example, the EMCD signal depends on the sample thickness, contrary to XMCD, and must be taken into account when comparing experimental results with theoretical simulations [2].

The observation that chiral electronic transitions break certain mirror symmetries in energy spectroscopic diffraction (ESD) led to the prediction that this breaking pertains in energy filtered high resolution imaging [3], thus opening the road to mapping electron spins of individual atomic columns under high resolution conditions in a conventional TEM. Spin up /spin down magnetisation of the specimen translates into characteristic shifts of the intensity maxima which do not exist in the elastic image. This was experimentally demonstrated on magnetite [4], see Fig.2.

One of the intriguing consequences of EMCD is that the outgoing probe electrons have topological charge with quantum number m. Such electrons exhibit a phase singularity and carry quantized orbital angular momentum $\hbar_m$, quite similar to the recently discovered vortex electrons [5,6].

After a synopsis of the different techniques of EMCD [7], applications such as the detection of magnetic moments on the nm-scale [8], studying individual magnetic nanoparticles and metallic thin film samples, and the applicability of sum rules [9,10] are discussed.

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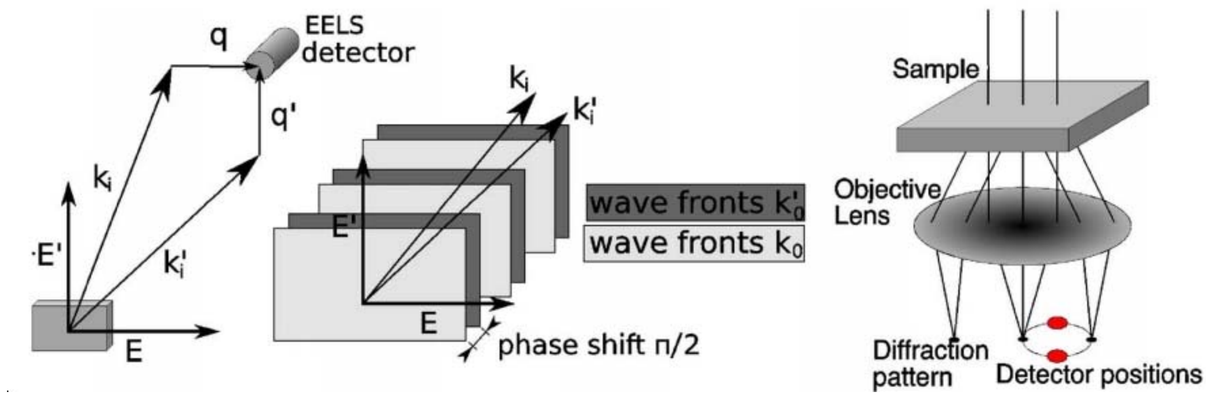

Figure 1: Left: Basic setup for EMCD conditions in the TEM in three steps: 1) coherent superposition of two plane waves (Bragg reflections); 2) positioning the spectrometer entrance aperture such that **q** ⊥ **q** and q=q'; and 3) setting the phase shift between the two incident electron waves to π/2. Right: Scheme of the electron trajectories and diffraction plane. The full circles show the detector positions for which the condition q=q' is fulfilled. As they select transitions of opposite chirality, EMCD can be detected by acquiring spectra at the two positions and taking their difference.

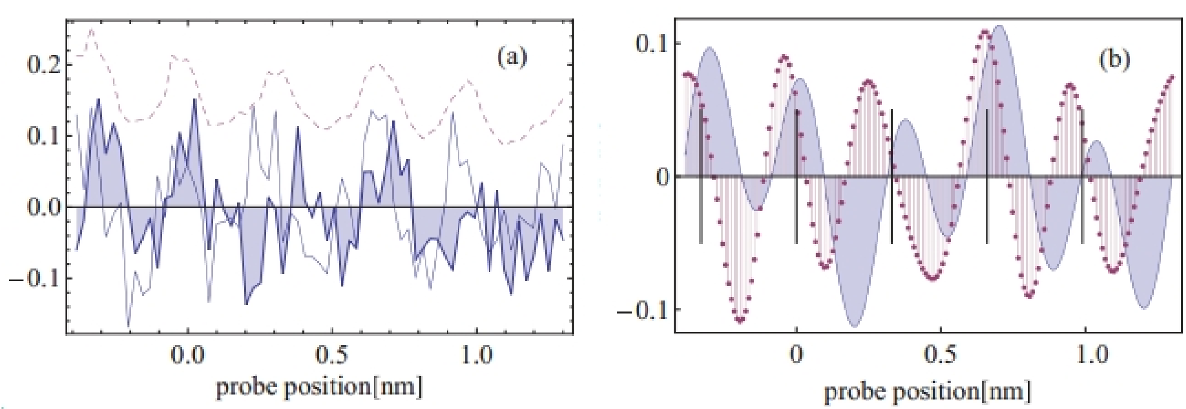

Figure 2: a) Relative intensity variations of the Fe L3 signal, scanning along a lattice plane in magnetite shows symmetry breaking of the upper/lower half detector, indicating column resolved spin polarisation. The filled curve is from the upper detector half, the empty curve from the lower one. The HAADF signal is superimposed (dashed) with maxima indicating the atom positions. b) Same scans after Fourier filtering shows the left/right shifts clearly. Atom positions are marked with vertical lines. From [3].

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