Electron vortex beams (EVBs) have attracted a lot of attention since their introduction to the transmission electron microscopy [1,2,3]. In [2] it was reported that EVBs should allow measurement of electron magnetic circular dichroism (EMCD; [4]). Our recent simulations of scanning transmission electron microscopy (STEM) seem to rule out utility of EVBs for measurement of EMCD, unless performed in atomic resolution [5].

The distribution of the EMCD signal in an intrinsic EMCD experiment [4] is anti-symmetric with respect to the mirror symmetry axes. As a consequence, a detector centred on a transmitted beam will not detect any net EMCD signal due to cancellation of positive and negative contributions. In contrast, vortex-induced EMCD can be measured at the transmitted beam. At the level of scalar-relativistic theory and assuming dipole-allowed transitions, we show that this only happens, when the discs in convergent beam electron diffraction (CBED) pattern overlap. Simulations in Fig. 1 illustrate the principle. The top row shows real-space probe wavefunction after passing through 10nm slab of bcc iron oriented in (001) zone axis. The beam diameter (FWHM is indicated in the top) is gradually reduced from left to right. Corresponding elastic CBED pattern shows discs, which eventually start overlapping, as the beam diameter is reduced. In the third row there is energy-filtered Fe-L₃ diffraction pattern, which acquires chirality once the CBED discs start overlapping. Finally, bottom row is the distribution of EMCD signal in the diffraction plane. Note the symmetric component of EMCD developing in the middle, once CBED discs start overlapping.

There are several parameters, which influence the inelastic scattering of EVBs: acceleration voltage, beam diameter, EVB angular momentum and a distance of the beam from an atomic column. Optimum may vary as a function of crystal thickness, structure and orientation. We fixed the latter two to (001) zone axis of bcc iron. All the other parameters were independently varied. The results of the optimization are summarized in a condensed form in Fig. 2. The best conditions are predicted for 10nm slab of bcc iron using an EVB of FWHM diameter 1.6Å with an angular momentum 1ħ at acceleration voltage 200keV, using an annular detector of inner (outer) diameters of 1G (5G), respectively, G=(100). These values appear to be reachable with state-of-the-art STEM instruments available today [6].


Acknowledgement: We acknowledge Swedish Research Council and Swedish National Infrastructure for Computing.
Fig. 1: Scattering of EVB with angular momentum $1\hbar$ on a 10nm thick bcc Fe crystal oriented along (001) zone axis. Beam diameter is shown by a violet label. Top rows shows scattered EVB wavefunction, elastic diffraction pattern (2nd row), energy filtered diffraction pattern at Fe-L$_3$ edge (3rd row) and the EMCD distribution in the diffraction plane (bottom).

Fig. 2: Optimization of vortex-beam EMCD as a function of acceleration voltage $V_{acc}$ and angular momentum $\langle L_z \rangle$. Optimal beam diameter and inner aperture diameter $R_{in}$ are shown in 4th and 3rd row. Resulting absolute and relative strength of EMCD are shown in the 1st and 2nd row, respectively. The overall optimum is the white square in the top left panel.