Internship Proposal

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Thesis possibility after internship: YES
Funding: NO

Title : Singular wave-based electron spectroscopy

Many condensed matter systems possess symmetries such that their response to electromagnetic stimuli depends on those stimuli polarization. Investigating (linear or circular) dichroic responses, is therefore invaluable for exploring multiple physical properties, be they structural, morphological, electronic or magnetic.
The traditional approach to studying dichroism is to use a polarized photon beam, in energy ranging from the visible to X-rays. The great success of this approach relies on several key assets: the high brilliance of laser or synchrotron sources and a well-established body of theory for describing the associated spectroscopies. Nevertheless, such spectroscopies generally suffer from a lack of spatial resolution, which limits their applicability for many systems. Electron spectroscopy, as practiced in electron microscopes, has much in common with optical techniques in the visible or X-ray spectral range. The use of electrons – within the framework of electron energy loss spectroscopy, EELS- instead of photons enables atomic or even sub-atomic spatial resolution to be achieved, performance unattainable with optical spectroscopy. In particular, X-ray-based magnetic dichroism (XMLD, XMCD) is limited to a resolution of around 10 nm, making electron spectroscopies the natural candidates for improving resolution by a factor of 100. In the visible range, dichroic measurements would be improved to reach a typical $\lambda/100$ spatial resolution. Unfortunately, several limitations have hampered the success of these techniques so far: their limited spectral resolution, the difficulty of creating specially designed electron waves that are intrinsically unpolarized but replicate the effect of optical polarization for electrons, and the lack of a comprehensive theoretical framework for accounting for this pseudo-polarization.
We have recently developed such a framework in the optical regime [Lourenço-Martins et al., Nature Physics 17 598 2021], and predicted that the linear and circular local density of electromagnetic states could be measured in the visible range, given eventually access to the local photon spin density. In parallel, we have just acquired a so-called phase-plate, which is a tool allowing engineering of the incident beam electron wavefunction.
In this project, we intend to use such a tool to produce two main types of electron wave functions that are predicted to mimic electron beam polarization states, namely so-called vortex beams (for circular polarization) and π beams (for linear).
The experiments with be performed in the CHROMATEM electron microscope, one of the few in the world with sufficient spectral resolution (of the order of 5 meV) to approach the performance of optical means, while at the same time possessing nanometric or even atomic spatial resolution.
Proof of principle experiments on artificial nanometric optical structures or condensed matter systems whose symmetry can be easily manipulated, thus making it easy to test the electron/matter interaction theories of systems associated with large linear or circular dichroic signals.

The project will include instrumental, experimental and theoretical aspects, and is therefore aimed at an inquisitive and motivated candidate.