How the symmetry of x-rays reveals the asymmetry of matter

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X-ray spectroscopies performed at synchrotron light sources, such as X-ray Absorption Spectroscopy (XAS) and Resonant Inelastic X-ray Scattering (RIXS) are powerful tools to study complex materials, due to their chemical selectivity that allows disentangling the respective contributions of different atomic species [1]. In this talk, I will show how the use of incident polarized x-rays (either linear or circular) can allow a deeper understanding of the electronic structure and reveal emergent properties. X-ray dichroism is defined as the difference in the x-ray cross-section measured for two polarization states of the incident light (vertical vs horizontal linear polarizations or left vs right circular polarizations). There exist different types of dichroisms that depend on the symmetry of the light-matter interaction operator with respect to time-reversal symmetry and to space inversion (also called parity) symmetry. While parity is broken in non-centrosymmetric crystals, time-reversal symmetry can be broken in materials either by spontaneous magnetic ordering or by the application of an external magnetic field. Different combinations yielding to different measurable dichroisms are therefore possible, the most popular certainly being X-ray Magnetic Circular Dichroism which is measured in centrosymmetric ferro/ferrimagnetic materials and provides access to the ground state spin and orbital magnetic moments of the absorbing atom. Other types of X-ray dichroisms, such as X-ray Natural Circular Dichroism, X-ray Magnetic Linear Dichroism or X-ray Magneto-Chiral Dichroism, have been so far less explored, despite their intrinsic high potential in measuring ground state momenta that can be connected to magnetic and / or optical activity properties.

I will present some of the recent achievements made in the field of x-ray dichroisms and discuss remaining open questions and prospects. Examples will cover crystals with x-ray optical activity [2, 3] as well as remarkable magnetic materials, such as magnetite [4], single molecule magnets [5], nanoparticles [6], magnetic liquids [7] and magnetotactic organisms [8].

[1] F. M. F. de Groot et al. *Resonant Inelastic X-ray Scattering*. Nature Reviews Methods Primers, 4, 45 (2024).
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[3] N. Bouldi et al. *X-ray magnetic and natural circular dichroism from first principles: calculation of K- and* L_1*- edge spectra*. Physical Review B 96, 085123 (2017).
[4] H. Elnaggar et al. *Noncollinear Ordering of the Orbital Magnetic Moments in Magnetite.* Physical Review Letters 123, 207201 (2019).
[5] L. Poggini et al. *Engineering Chemisorption of* Fe_4 *Single-Molecule Magnets on Gold.* Advanced Materials Interfaces 8, 2101182 (2021).
[6] N. Daffé et al. *Nanoscale distribution of magnetic anisotropies in bimagnetic soft core-hard shell* $MnFe_2O_4@CoFe_2O_4$ *nanoparticles.* Advanced Materials Interfaces 4, 1700590 (2017).
[7] N. Daffé et al. *Bad Neighbour, Good Neighbour: How Magnetic Dipole Interactions Between Soft and Hard Ferrimagnetic Nanoparticles Affect Macroscopic Magnetic Properties in Ferrofluids.* Nanoscale 12, 11222 (2020).
[8] D. M. Chevrier et al. *Collective magnetotaxis of microbial holobionts is optimized by the three-dimensional organization and magnetic properties of ectosymbionts*. Proceedings of the National Academy of Sciences 120, e2216975120 (2023).