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Magnetic, electric and toroidal polarization modes describing the physical properties of crystals

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The symmetry of multiple magnetic phenomena, e.g. ferromagnetism, collinear ordering, spin reorientation, or canted antiferromagnetism, do not depend on the atomic positions. They depend only on the set of directions of magnetic moments, which we will call magnetic mode. We will present the complete classification of magnetic modes [1] based on the magnetic point groups used in two contexts: (i) the magnetic point group of the magnetic crystal class and (ii) the magnetic site symmetry point group of the Wyckoff position of interest. This classification gives restrictions to all previously mentioned phenomena [1,2]. Permutations of space inversion, $\bar{1}$, time inversion, 1', and space-and-time inversion, $\bar{1}$' allow to extend magnetic modes classification to the electric, and toroidal polarisation modes classification [3]. To highlight magnetic, electric and toroidal polarisation modes new notation of magnetic point groups was introduced [3].
Conclusion from classifications of magnetic, electric and toroidal polarisation modes is that there are multiple materials which crystal symmetry disagree with phenomena experimentally observed inside them. This gives strong motivation to re-examine their crystal structure. For instance most of the rare-earth orthoferrites, $RFeO_3$, show spin reorientation transition, e.g. $Pb'n'm(\Gamma_4) \rightarrow Pbn'm'(\Gamma_2)$ for R = Nd, Sm, Tb, Ho, Er, Tm, Yb and $Pb'n'm(\Gamma_4) \rightarrow Pbnm(\Gamma_1)$ for R = Dy, Ce. General conclusion from the continuous magnetic modes'classification is that spin reorientation is not possible within orthorhombic symmetry. The predicted monoclinic $NdFeO_3$ symmetry [1, 3] leads to a nontrivial Dirac multipoles motif which could be confirmed using neutron diffraction or resonant x-ray diffraction [4].
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Primary author: FABRYKIEWICZ, Piotr (Institute of Crystallography, RWTH Aachen University, Germany and Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Garching, Germany)

Co-authors: SOSNOWSKA, Izabela (Faculty of Physics, University of Warsaw); PRZENIOSŁO, Radoslaw (Faculty of Physics, University of Warsaw)

Presenter: FABRYKIEWICZ, Piotr (Institute of Crystallography, RWTH Aachen University, Germany and Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Garching, Germany)

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