Structural and magnetic chiralities in a langasite compound

A novel, doubly-chiral magnetic order is found in the structurally-chiral langasite compound $Ba_3NbFe_3Si_2O_{14}$. Our neutron scattering experiments show that the magnetic ground state exhibits a unique sense of rotation of the spins along helices, as well as a unique sense of rotation of the spins around small triangular units in the plane perpendicular to the helices. The spin-wave excitations emerging from this totally-chiral magnetic order present fully chiral spin-correlations over the whole energy spectrum.

Ubiquitous in nature, chirality (from the Greek word χειρ for "hand") is the geometric property of an object according to which it exists in two distinct states called enantiomorphs that are images of each other in a mirror. Hands, sea-snail shells, biological molecules like amino acids, even the electroweak interaction, are chiral. In magnetism, an example of chirality is found in helical ordering, where it is related to the sense of rotation of the magnetic moments around a helix axis. Another example of magnetic chirality is the clockwise/anticlockwise sense of rotation of three spins having 120° relative orientations, each situated at the summit of a triangle (the usual signature of "magnetic frustration"). Usually, in materials presenting such spin arrangements, two domains of opposite chirality coexist and are equally populated, yielding a state of zero macroscopic chirality.

A novel chiral magnetic order is found in the langasite compound $Ba_3NbFe_3Si_2O_{14}$, single crystals of which are "enantiopure", that is they grow in an atomic arrangement that always shows a single macroscopic structural chirality. Unpolarized neutron diffraction has shown that the magnetic moments are distributed in a 120° arrangement over small triangle units whose centres form a triangular lattice. This order is helically modulated in the direction perpendicular to the triangles. Techniques based on polarized neutron diffraction have proved that a single triangular magnetic chirality together with a single helical magnetic chirality is stabilized in an enantiopure $Ba_3NbFe_3Si_2O_{14}$ single crystal. We have analyzed the relation between the structural chirality, the 120° spin arrangement, the formation of the helices, and the selection of the magnetic chiralities. It is expected that such totally chiral magnetic states should optimize the potential magnetoelectric and multiferroic behaviours.

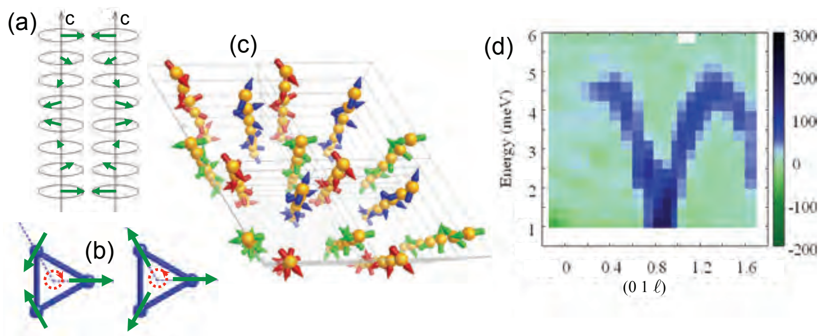

Figure caption: (a) helical chirality states (b): Triangular chirality states (c): 120° planar spin structure propagating helically in the perpendicular direction (d); Chiral inelastic scattering measured with polarized neutrons revealing the full chirality of one spin wave branch.

This unique chiral (magnetic and structural) order generates spin waves (elementary excitations) with remarkable properties. Spin waves correspond to coherent motion in space and time of small out-of-equilibrium spin components. In $Ba_3NbFe_3Si_2O_{14}$, they are visualized in the reciprocal space by two branches rising at finite energy from the elastic Bragg positions characteristic of the magnetic order. Most remarkably, the spin wave branch that corresponds to the Fourier Transform of planar spin-spin correlations is found to be totally chiral. This is the first observation of chiral dynamics over the whole energy range of the spin-wave excitations in the absence of an external magnetic field. It highlights how the static chiral properties are extended to the dynamics.

CONTACTS

Virginie SIMONET
virginie.simonet@grenoble.cnrs.fr
Tel: +33 476 88 74 27

Rafik BALLOU
rafik.ballou@grenoble.cnrs.fr
Tel: +33 476 88 79 18

FURTHER READING

SINGLE DOMAIN MAGNETIC HELICITY AND TRIANGULAR CHIRALITY IN STRUCTURALLY ENANTIOPURE $Ba_3NbFe_3Si_2O_{14}$
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