

Quantum materials and magnetism

Scientific project for researcher training · CBPF

Motivation and objective

Understanding and controlling the interactions between charge, spin and orbital angular momentum is a central challenge in condensed matter physics. In quantum materials, interfaces and reduced-dimensional structures, these interactions can produce electronic and magnetic properties that strongly depend on composition, symmetry and geometry. Exploring this dependence enables investigations of new mechanisms for information transport and the formation of magnetic states with distinct stability and dynamics.

The objective is to investigate the generation, transport and conversion of angular momentum and the formation of topological magnetic textures, combining crystal growth, two-dimensional materials, nanomagnetism and theoretical modelling. This research is part of the Institutional Platform for Quantum Materials, Spintronics and Topological Structures for Emerging Technologies, coordinated by Flávio Garcia at CBPF, and offers research topics for master's and doctoral training.

Research areas

1 Spintronics and orbitronics

Investigate how charge currents generate and detect flows of spin and orbital angular momentum in materials and heterostructures. The focus is on distinguishing conversion mechanisms, understanding the role of spin-orbit coupling and identifying how interfaces, electronic edge states and dimensionality modify transport. Combinations of magnetic materials, metals and two-dimensional systems will be explored to establish relationships between electronic structure and conversion efficiency.

2 Crystal growth and quantum materials

Develop crystals and investigate how composition, crystal structure and sample quality determine their electronic and magnetic properties. Growth will be guided by scientific questions: which conditions favour a particular magnetic order, how does composition alter the relevant interactions, and how do these properties evolve as dimensionality is reduced? Crystals, layered materials and heterostructures will provide complementary systems for establishing these relationships and selecting materials for spintronics and orbitronics studies.

3 Nanomagnetism and topological magnetic textures

Study the formation, stability and dynamics of skyrmions, skyrmioniums and other magnetic configurations in planar, three-dimensional and curved systems. The relationships between confinement, curvature, anisotropy and the magnetic interactions that select each state will be investigated. The research will seek to identify stabilisation conditions and mechanisms for controlling these textures, as well as their response to fields and excitations, linking material geometry to possibilities for manipulating magnetisation.

4 Theory and multiscale modelling

Develop theoretical descriptions of electronic and magnetic properties, angular momentum transport and texture dynamics. First-principles calculations, transport models and micromagnetic simulations will connect microscopic interactions to observable behaviour. Theory will contribute both to predictions and the selection of promising systems, and to the interpretation of experimental results, through independent projects and opportunities for joint research.

Integration of theory and experiment

Each participant will develop a focused scientific question within one or more research areas. Experimental projects may investigate relationships between composition, dimensionality and magnetic or electronic response; theoretical projects may identify mechanisms, calculate properties and propose conditions for observing new behaviours. Joint discussion of results will guide material selection and the revision of hypotheses, keeping the physical problem at the centre of the work.

Methodological resources include crystal growth, thin-film deposition, exfoliation and transfer of two-dimensional materials, micro- and nanofabrication, X-ray diffraction, Raman spectroscopy, magnetometry, ferromagnetic resonance, magneto-optics, electronic transport and magnetic imaging, as well as first-principles calculations and micromagnetic simulations. The choice will depend on each project's research question.

Work plan and training

The initial stage will involve reviewing the literature, defining hypotheses and selecting the physical system. Experiments or calculations will then be developed, with critical analysis and regular discussion of results. The consolidation stage will involve integrating the conclusions, presenting them at seminars and scientific meetings, and preparing scientific publications.

Master's projects will focus on well-defined scientific questions, while doctoral projects will develop broader, original investigations. Research plans will be tailored to each participant's academic background and interests, with scientific supervision and integration into the team's research activities.

Expected outcomes

The project is expected to establish relationships between the structure, composition and properties of quantum materials; clarify angular momentum conversion mechanisms; and identify conditions for the formation and control of topological magnetic textures. The results should support publications, scientific presentations and postgraduate research, according to each participant's academic trajectory.

Training will focus on developing the independence needed to formulate problems, assess evidence and produce original results. Integrating participants into the team and the project's scientific collaborations will contribute to expanding knowledge and strengthening CBPF's postgraduate research in quantum materials and magnetism.