p-wave, spin-triplet, topological superconductivity in the ferromagnetic superconductors

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PhD may follow: Yes

Summary :

This master project, that should be continued as a PhD project, is focused on a particular class of strongly correlated superconductors, which are â€œspin-triplet/p-waveâ€• type superconductors, a highly sought-after state (e.g. it is necessary to generate Majorana quasiparticles). These p-wave superconductors are uranium-based systems (URhGe or UCoGe for this project), which are also ferromagnetic superconductors: both systems become first ferromagnetic on cooling, at around 9 or 3K respectively, and they remain so when they become superconducting (below 0.25K or 0.5K respectively).

Today, these ferromagnetic superconductors appear as the best ones to explore the rich physics of spin-triplet pairing, as they combine an uncontested p-wave state together with high-purity samples. The aim of the project is to get a much deeper knowledge of the p-wave order parameter (the â€œd-vectorâ€•) in UCoGe. During the M2 internship we will:

- explore the coupling of the d-vector to the magnetic field, which leads to the re-entrant/reinforced superconducting state, through thermal dilatation measurements.
- explore the conditions for the observation of the topological properties of the superconducting state, measuring the thermal Hall effects.

All measurements will be performed in dilution refrigerators, on crystals grown in the group. A strong theoretical support is also available in the laboratory.

Full description :

Superconductivity is one of the liveliest fields in basic research on condensed matter physics, due to the continuous discovery of new families of superconductors challenging our understanding of this phenomena. Most of these new families of superconductors are also strongly correlated electron systems, such as the high-Tc cuprates, iron pnictides, heavy fermionsâ€¦ They share the same key questions concerning their superconducting and normal state properties, and a central one is the origin of the pairing mechanism, which arises dominantly from electron-electron interactions, rather than from electron-phonon interactions. However, recently, it has been realized that the superconducting state of these unconventional superconductors could also have very peculiar topological properties, connected either to the band structure of the material or to the precise nodal structure of the superconducting gap.

This master project, that should be continued as a PhD project, is focused on a particular class of heavy fermion superconductors, which have the appealing feature of being â€œspin-triplet/p-waveâ€• type superconductors, a highly sought-after state (e.g. it is necessary to generate Majorana quasiparticles). These p-wave superconductors are uranium-based systems (URhGe and UCoGe for this project), which are also ferromagnetic superconductors: both systems become first ferromagnetic on cooling, at around 9 or 3K respectively, and they remain so when they become superconducting (below 0.25K or 0.5K respectively).

Moreover, in both systems, superconductivity seems to be reinforced under magnetic field, contrary to the situation of all other known superconductors. Indeed, URhGe shows a spectacular reentrance, and UCoGe a spectacular enhancement of superconductivity, when the ferromagnetic order vanishes as function of the applied magnetic field (see figure).

Today, these ferromagnetic superconductors are probably the best one to explore the rich physics of triplet pairing, as they are the only one combining an uncontested p-wave state together with high-purity samples. The aim of the M2 project is to get a much deeper knowledge of the p-wave order

parameter (the â€œd-vectorâ€•) in UCoGe. Two main axes will be started during the M2 internship:
- exploring the coupling of the d-vector to the magnetic field, which leads to the re-entrant/reinforced superconducting state, through thermal dilatation measurements.
- exploring the conditions for the observation of the topological properties of the superconducting state, measuring the thermal Hall effects.

With thermal expansion, we want to explore the superconducting state as function of magnetic field with unequalled precision: most likely, in the region where ferromagnetism collapses inside the superconducting state, the spin-triplet p-wave order parameter has to evolve strongly, and we even expect the occurrence of phase transitions between different superconducting phases.
UCoGe is predicted to be a â€œWeyl superconductorsâ€•, with nodal chiral excitations along the easy magnetization c-axis. Low energy surface states are then expected, that might concentrate in the chirality domain walls. The thermal Hall effect measurements that will be performed during the M2 internship is a very sensitive and selective probe of the electronic low energy excitations.
All measurements will be performed in dilution refrigerators, on crystals grown in the group. A strong theoretical support is also available in the laboratory.

Requested skills :
A strong tatse for instrumentation, experimental physics, quantum physics, ability to discuss with theorists and face complex problems.