Time reversal symmetry breaking superconductivity

Michael Smidman

[1] Center for Correlated Matter and Department of Physics, Zhejiang University, Hangzhou 310058

The breaking of gauge symmetry at the superconducting transition leads to many of the characteristic properties of superconductors, such as the Meissner and Josephson effects. In unconventional superconductors, additional symmetries of the normal state are also often broken, which cannot be accounted for by Bardeen-Cooper-Schrieffer (BCS) theory. In some cases, time-reversal symmetry (TRS) is broken, which is manifested by the spontaneous appearance of small magnetic fields in the superconducting state, and can be detected using techniques such as muon-spin relaxation or measurements of the Kerr effect [1]. The most notable examples of TRS breaking superconductors are a handful of strongly correlated, magnetic materials, such as Sr_2RuO_4, and some uranium-based heavy fermion materials, where unconventional superconducting pairing states are readily anticipated. However, in recent years broken TRS has been found in a number of superconductors which otherwise appear resemble their conventional counterparts [1], such as $LaNiGa_2$, La_7Ir_3 and several Re-based superconductors. In particular, the superconducting gap is generally fully open over the whole Fermi surface, and in many cases, the origin of the TRS breaking in the superconducting state remains to be determined.

In order to understand the origin of broken TRS in this class of superconductors, we have utilized a number of techniques. Muon-spin relaxation is used to probe for the presence or absence of TRS in the superconducting state, and to estimate the size of any internal fields. Meanwhile, both transverse field muon-spin rotation and the tunnel-diode oscillator based method are employed to measure the temperature dependence of the magnetic penetration depth, so as to characterize the superconducting gap structure. These results have been combined with theoretical analyses in order to constrain the possible pairing states, and to account for the origin of the TRS breaking in these compounds.

[1] Sudeep Ghosh, Michael Smidman, Tian Shang, James F. Annett, A. D. Hillier, Jorge Quintanilla and Huiqiu Yuan, Recent progress on superconductors with time-reversal symmetry breaking, *Journal of Physics: Condensed Matter* (In Press). Accepted manuscript available at: https://iopscience.iop.org/article/10.1088/1361-648X/abaa06