Magnetic impurities in superconductors: Role of many-body interactions

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Abstract
Understanding the interplay between individual magnetic impurities and superconductivity is crucial for bottom-up construction of novel phases of matter such as topological superconductivity and Majorana edge states, as well as to exploit the local response as a probing tool. For decades, the description by Yu, Shiba and Rusinov (YSR) of single spins in a superconductor and its extension to include quantum effects has proven highly successful: the pair-breaking potential of the spin generates sub-gap electron- and hole excitations that are energetically equidistant from zero. By tuning the energy of the sub-gap states through zero, the impurity screening by the superconductor makes the ground state gain or lose an electron, signalling a parity breaking quantum phase transition.

Here, we present a set of scanning tunneling microscopy (STM) measurements that explicitly invalidate the classical YSR paradigm, and we propose an interpretation in terms of a multi-orbital Anderson impurity model [1]. In particular, we show that in multi-orbital impurities, electronic correlations can conversely lead to a quantum phase transition where the impurity mean occupation changes dramatically, without significant effect of the screening by the superconductor. This finding implies that the YSR treatment is not always valid, and that intra-atomic interactions, particularly Hund's coupling that favours high-spin configurations, are an essential ingredient for understanding the sub-gap states. Our work belongs to a renewed effort to characterize the quantum behavior of magnetic impurities in superconductors by employing toy-models that incorporate many-body correlations [2,3].

References

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Figures

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Figure 1: Normalised differential conductance directly above the Fe impurity when approaching the tip closer (top to to bottom). As soon asthe first state crosses zero, the intensity of all others is affected. The dashed grey lines mark the gap edges.