"Magnetic properties of Majorana fermions"

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Majorana fermions were predicted by Majorana in 1937. These are fermions whose wavefunction is real, they are therefore their own anti-particle. Until recently, no elementary particle has been proved to be a Majorana fermion. In condensed matter physics, there have been several new proposals to realise Majorana fermionic excitations. Thus it was shown that they can emerge as excitations inside the gap of some exotic topological superconductors or in a semiconductor with a strong spin orbit coupling in the presence of a Zeeman field in proximity of a normal superconductor. Recently some experimental observations seem to indicate also the formation such non-trivial excitations.

The goal of this PhD project is to study the effect of the magnetic fields for the formation of Majoranas, as well as the magnetic structure of these states. We know that a Zeeman field oriented in a certain direction contributes to the formation of Majoranas, but it is not clear if the direction of the field will affect the conditions under which the Majorana states can form, especially in two-dimensional systems. Moreover, it is believed that the orbital effects of the field may destroy Majoranas, though a thorough analysis has not been performed to this purpose. We want to perform such an analysis for one-dimensional and two-dimensional systems, and establish if the orbital effects are destroying the Majoranas or if they can eventually benefic for their formation and under what conditions. The extreme limit, that of the quantum Hall effects is of particular interest, as some preliminary experimental and theoretical works indicate the possibility to generate interesting states in the presence of both quantum Hall effect and superconductivity, especially for systems such as graphene. For graphene the effect of orbital fields arising from changes in the graphene planarity and from the corresponding local curvature will also be investigated.

The tools that we will apply to investigate these topics are both analytical and numerical. An important concept to apply is the Majorana polarization, introduced in a recent work to describe the formation of Majorana fermions. A good knowledge of quantum field theory, Green's functions, many body physics, as well as solid state physics is necessary.