# Interaction effects on topological properties of multiterminal Josephson junctions

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**PhD may follow:** Yes

**Summary :**

There is currently an active search for new phases of matter that admit topologically protected edge states. A promising route to realize them consists in combining conventional materials into appropriate heterostructures. Multiterminal Josephson junctions between conventional superconductors may be considered as topological materials themselves. As an example, 4-terminal junctions can accommodate topologically protected zero-energy bound states, which form so-called Weyl singularities. Their existence may be revealed through a quantized transconductance, like in the quantum Hall effect, but without magnetic field. The aim of the project will be to explore further this recent idea by investigating theoretically the robustness of this prediction in the presence of local Coulomb repulsion within the junction. In particular, the fate of Weyl singularities will be analyzed within an actual quantum-dot model for the junction.

**Full description :**

Topological phases of matter have attracted much interest in recent years. The existence of topological insulators has been unambiguously demonstrated in a variety of experiments [1]. First reports on the existence of Weyl semimetals have started to appear [2]. However, conclusive evidence for the realization of topological superconductors is still missing. Much of the progress in the field has been fuelled by the insight that, rather than relying on exotic material properties, topological phases may be engineered by combining different more conventional materials [3].

As we have predicted recently, multiterminal Josephson junctions may be considered as topological materials themselves [4]. Indeed, there is an intimate connection between the Josephson effect - a non-dissipative current flowing between two superconductors separated by an interface - and the formation of Andreev bound states localized near that interface and whose energy is below the superconducting gap. Topology teaches that there is more information encoded in the wavefunctions than in the bulk energy spectrum [5]. This is also the case for Andreev states. In particular, we showed that n-terminal Josephson junctions with conventional superconductors may provide a straightforward realization of tunable topological materials in n-1 dimensions. Namely, for n >= 4, the Andreev bound state spectrum of the junction can accommodate Weyl singularities in the space of the n-1 independent superconducting phases, which play the role of band structure quasi-momenta. Such Weyl singularities correspond to topologically protected zero-energy states.

In multiterminal Josephson junctions, the presence of Weyl singularities enables topological transitions that could manifest themselves experimentally as changes of the quantized transconductance, in units of 4e2/h, between two voltage-biased terminals. The quantized transconductance probes the first Chern number of two-dimensional slices through the space of the n-1 phases. Thus, it is similar to the quantum Hall effect.

The aim of the project will be to explore further the theoretical idea introduced in our work and to investigate the conditions for its experimental implementation. In particular, we propose to study the robustness of our prediction in a specific model for a 4-terminal junction, which consists of a small number of discrete levels that are weakly coupled to the leads. The candidate will start by exploring the conditions for the appearance and merging of Weyl points in the absence of interaction. She/he will then consider which modifications of the spectrum may be expected in the presence of local Coulomb repulsion. Following the recent suggestion of the interaction-induced emergence of parafermions in 2-terminal junctions between topological superconductors [6], she/he will study whether a fractional quantum Hall effect could be envisioned in a 4-terminal junction.

In the long-term, the relative simplicity of topological multiterminal Josephson junctions could be important for applications in the growing field of quantum engineering with superconducting devices. Indeed, the topological nature of the investigated effects could lead to applications in the fields of topologically protected quantum computation, as well as metrology.

[1] M.Z. Hasan and C.L. Kane, Rev. Mod. Phys. 82, 3045 (2010), http://arxiv.org/abs/1002.3895
[2] S.Y. Xu et al., Science 349, 613 (2015), http://arxiv.org/abs/1502.03807
[3] J. Alicea, Rep. Prog. Phys. 75, 076501 (2012), http://arxiv.org/abs/1202.1293
[4] R.-P. Riwar, M. Houzet, J.S. Meyer, and Yu. V. Nazarov, Nature Commun. 7, 11167 (2016), http://arxiv.org/abs/1503.06862
[5] M. Nakahara, "Geometry, Topology and Physics", IOP Ed.
[6] Fan Zhang and C.L. Kane, Phys. Rev. Lett. 113, 036401 (2014), http://arxiv.org/abs/1404.1072

see also: http://inac.cea.fr/en/Phocea/Vie_des_labos/Ast/ast.php?t=fait_marquant&id_ast=1173

**Requested skills :**

The theory project will be performed mainly by using the analytical tools of condensed matter field theory. It may also involve numerical aspects.

Interested candidates should have a good basis in quantum mechanics, statistical physics, and solid state physics.