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Spin orbit coupling effects in a graphene Josephson junction

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We study a Graphene Josephson Junction (GJJ) where the inner graphene layer is subjected to a strong Spin-Orbit Coupling (SOC) by proximity effect. This could be achieved, for example, by growing the graphene layer on top of a transition metal dichalcogenide, such as WS2. This setup is experimentally relevant for applications in Josephson junctions since it was shown that it can host superconducting current for magnetic fields of up to 10 Tesla. The SOC terms heavily modify the band structure of the inner graphene layer, inducing different topological phases with associated helical or quasi-helical edge modes. In our work, we focus on the ballistic and short junction limits and, in particular, we study the effects of the SOC interaction on the supercurrent. We follow an analytical approach based on the continuum model for the bulk contribution. We find that there are combinations of spin-orbit couplings that, by opening a gap (topological or not) in the system, drastically suppress the bulk supercurrent. At the same time, other combinations enhance it, effectively acting as chemical potential. For the edge contribution, instead, we made us of a tight-binding procedure based on the Kwant python package. We find no difference in intensity between the supercurrent carried by topological helical edge modes and non-topological dispersive quasi-helical ones: they both contribute as quasi-transparent ballistic modes. By including localized magnetic impurities along the edges we have also analysed their robustness. Because of the different localization properties, the supercurrent carried along the zigzag edge was found to be very sensitive to even a single impurity while, remarkably, the supercurrent carried along the armchair one showed an extreme resilience. Finally, we find that, in a junction configuration, there is virtually no difference between intermediate edges terminations and the zigzag one, giving more experimental relevance to the dispersive quasi-helical edge modes.