Aharonov-Bohm and Aharonov-Casher effects of nonlocal and local Cooper pairs

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Abstract

In recent years, there is substantial progress in creation of specially separated spin entangled electrons in solid state using the splitting of Cooper pairs [1], which is necessary ingredient of quantum communication and computing. It is also possible to generate a Josephson supercurrent form by split nonlocal Cooper pairs [2]. This new Josephson current required further studies especially its interference properties, since these can provide quantum gates. While the behavior of single electrons under the influence of Aharonov-Bohm (AB) and Aharonov-Casher (AC) effects is well understood, it raises the question of the impact of these effects on nonlocal superconducting Cooper pairs that for s-wave superconductors are in spin singlet state. For electrons in solid-state, the AC effect can be caused by the Rashba spin-orbit interaction. We analyze two systems: (i) a normal ring, where a single electron interference is possible and (ii) two parallel nanowires connected to two superconducting electrodes, where a single-electron interference can be absent but a cross Andreeev reflection is possible. At low transmission for both considered systems, we can link the AB effect only to local Cooper pairs and the AC effect to nonlocal Cooper pair transport [3]. This is a rather surprising effect since Cooper pairs in the singlet state have no magnetic moment that is necessary ingredient of the AC effect. We demonstrate that by inserting quantum dots in the two nanowires we can obtain different AC phases for the nonspin-flip and spin-flip transport processes that leads to a beating in the AC effect. [1] L. Hofstetter, S. Csonka, J. Nygård, and C. Sch´onenberger, Nature 461, 960 (2009).

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