Ferromagnetic 0-π Junctions as Classical Spins

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Macroscopic devices that act as simple two-level systems are an attractive possibility, with applications including qubits and models of the Ising spin system. One such macroscopic device, the SQUID, has been shown to undergo quantum coherence between two degenerate macroscopic states [1]. The conditions for degeneracy are typically reached by applying an external magnetic flux or current. However, it is desirable for degeneracy to be reached without such an externally applied field. This can be done using superconducting π-rings, rings with at least one Josephson weak link and an intrinsic π-phase shift. Further, it has been proposed that "quiet" superconducting qubits, qubits with degenerate states but no circulating supercurrents, can be produced using combinations of 0- and π-rings [2]. A basic building block of such quiet qubits, a π/2 shifted SQUID, has been demonstrated recently [3].

The first superconducting π-rings, which took advantage of the momentum dependence of the pairing wavefunction in the high-Tc superconductors, were made using technologies which would be difficult to extend to many devices. Recently a ramp-edge junction technology that allows for photolithographic fabrication of π-shift devices and arrays of great complexity has been demonstrated [3]. Moreover, it has recently been demonstrated that π-rings can also be fabricated using Josephson junctions with ferromagnetic layers in the tunnel barriers [4].

The current paper uses the ferromagnetic tunnel junction technique to make 0-π junctions, which spontaneously generate a half-flux quantum Josephson vortex at the point where the intrinsic phase changes from 0 to π. Such vortices have also been demonstrated using unconventional superconductors [5]. The half-flux quantum Josephson vortex is a close analog to a classical spin, in that it has two degenerate states in the absence of an externally applied flux. There must always be such a vortex at the 0-π meeting point, and vortices with higher quantum numbers (3/2, 5/2, etc.) are energetically unstable.In the current paper the actual junction geometry is a little hard to visualize, the 0 regions arising from defects threading the ferromagnetic layer (π-region) in the tunnel junction. Nevertheless, Della Rocca and his co-workers demonstrate the existence of half-flux quantum Josephson vortices in their devices, and show that they have some of the properties of a classical spin: a 2-fold ground state degeneracy that can be lifted by the application of an external applied magnetic field. The presence of the Josephson vortex is detected by measuring the current-voltage characteristics of a second conventional junction in a clever back-to-back double junction geometry. It seems very likely that similar techniques can be used to make 0-π junctions in a more controlled geometry. This increases the options for fabricating π-shift devices with great flexibility and complexity.

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