Persistent Current in a Ring Coupled to an External Fermionic Reservoir

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Coherence plays a crucial role for the existence of persistent current. It has been shown experimentally and theoretically that decoherence introduced by either finite temperature or disorder suppresses the persistent current [1].

Exchange of particles with an external reservoir represents another source of decoherence for a mesoscopic system. In this work we study how that kind of decoherence affects the persistent current in an ideal mesoscopic ring.

The theoretical model consists of an ideal ring coupled to the fermionic reservoir by tunneling. The tunneling operator does not conserve the angular quantum number. Within the adopted model both the strength of coupling and the number of ring states coupled to the reservoir can be varied. We found that the persistent current is rather robust against the decoherence due to the particle exchange with the reservoir. A similar system has been investigated previously in the frame of the scattering matrix approach [2]. However, the effects predicted in the present paper have not been discussed there.

As one varies the strength of the coupling to the reservoir, there are two regimes with qualitatively different behavior of the persistent current. In the weak coupling regime, where the broadening of each ring state is less than the interlevel distance, the persistent current gets suppressed with growing coupling (see Fig. 3).

In contrast, in the strong coupling regime, where the broadening of a single level exceeds the interlevel distance, the mixing of states by the coupling to the reservoir leads to a qualitatively different behavior of the persistent current. In this regime, long-living states develop that are localized in the ring. These states show up as sharp peaks in the density of states (DoS) (see Figs. 1,2). The simplified model, which only considers the coupling of two ring states to the reservoir could be solved analytically by diagonalizing the effective Hamiltonian. In the strong coupling limit one state decouples completely from the reservoir, thus producing a nonvanishing persistent current even if the tunnel coupling is much stronger than the interlevel distance (Fig. 1, 3a). The formation of a long-living state at strong tunnel coupling to the reservoir is analogous to the well-known Dicke-effect in optics. Recently, similar effects have been predicted in context of resonant scattering and resonant tunneling in solid state systems [3]. For a finite number of levels coupled to the reservoir, the persistent current saturates at a nonzero value as the coupling becomes very strong. Only if all the levels in the ring are coupled to the reservoir, the complete suppression of the persistent current is achieved (Figs. 2, 3b).

References

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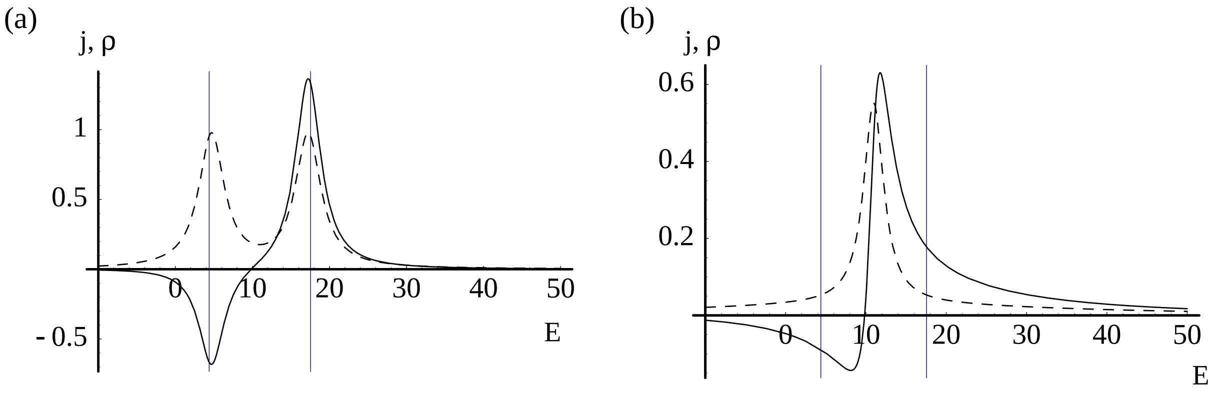

Fig. 1: Current density (full line) and density of states (DoS) (dashed lines) for coupling of the two lowest lying ring states. Gridlines show the energies of states in the isolated ring. (a) Weak coupling regime: Current density and DoS are broadened around the eigenenergies of the isolated ring states. (b) Strong coupling regime: Two hybridized states develop. One state decouples from the reservoir (sharp maximum in DoS). The other state hybridizes strongly with the reservoir and forms a broad background in DoS.

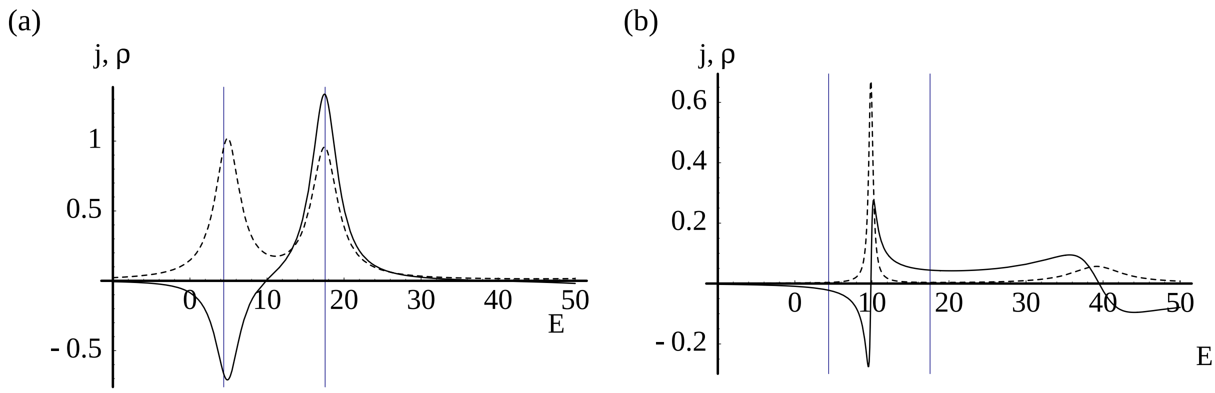

Fig. 2: Current density (full line) and DoS (dashed line) for coupling of all ring states. Gridlines show the energies of isolated ring states. (a) Weak coupling: The same behavior as in Fig. 1a. (b) Strong coupling: DoS shows sharp peaks and a broad background. The current density has an asymmetric form around the energy of each decoupled state and changes its sign abruptly.

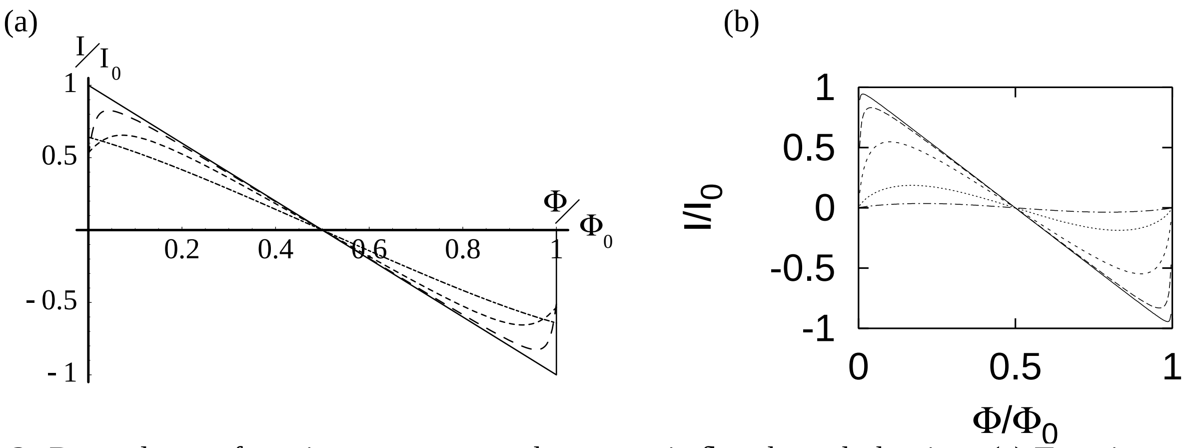

Fig. 3: Dependence of persistent current on the magnetic flux through the ring. (a) Two ring states couple to the reservoir. For weak coupling the current gets smoothed and decreases with increasing coupling. In the strong coupling regime the current saturates. The sawtooth form of the current is restored. (b) All ring states couple to the reservoir. The persistent current is suppressed with increasing coupling and disappears in the strong coupling regime.