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Exploring the role of impurities on the supercurrent stability in atomic superfluid rings

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Persistent currents are long-lived metastable states characterized by quantized circulation, denoted by the winding number w. The main topic of this talk is the investigation of the stability of these supercurrents in the presence of impurities and throughout the BEC-BCS crossover. For this purpose, we solve the Gross-Pitaevskii equation in the BEC regime and employ a time-dependent density functional theory for the unitary Fermi gas (UFG) and BCS limits. Our results show that when the initial winding number w0 exceeds a critical value, the supercurrent becomes unstable and w, as well as the flow energy or current, decays over time. The dissipation mechanism associated with vortex generation is present across all interaction regimes; however, in the BEC limit, it is the sole mechanism responsible for the decay of the persistent current. In contrast, in the UFG and BCS regimes, an additional dissipation channel emerges—the pair-breaking mechanism—which reduces the superfluid fraction and thus the current stability. Notably, vortex emission in the BCS regime is accompanied by Cooper pair breaking that extends beyond the vortex core. This pair-breaking process prevents the imprinting of a persistent current with a winding number above a threshold, whose value decreases as the system approaches the BCS regime. Furthermore, we explore how the number and distribution of impurities affect the critical winding number and the dissipation of flow energy. We find that in the BEC limit, the critical winding number increases with impurity density, whereas near the BCS regime, it is constrained by the pair-breaking threshold regardless of impurity characteristics.

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