Pushing a Fermi superfluid through a thin optical barrier: from coherent tunneling to phase slips

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We study, across the whole BEC-BCS crossover, the dynamics of a Fermi superfluid flowing in the presence of a thin barrier ($d{\sim}5k_F^{-1}$). For this purpose, we produce a two-component ^{6}Li quantum gas [1] in a double-well potential created by superimposing a repulsive optical barrier of micrometric thickness on the harmonic optical trap. The dynamics is started by establishing an initial difference in the number of particles between the two wells. We explore different regimes, from a BEC of composite molecules to a BCS superfluid, by magnetically controlling the two-spin interaction by means of a Fano-Feshbach resonance. By tuning the barrier height and the starting imbalance, we observe either Josephson tunneling or dissipation via phase slips. In the former case, occurring for small amplitude oscillations as the barrier height reaches or exceeds the chemical potential, we find that the superfluid current exhibits a maximum at the unitarity, as a consequence of the interplay between phonon excitations and pair-breaking [2–4]. The phase slip mechanism is instead observed for larger starting imbalances and is associated to the superfluid flow dissipation caused by the formation of topological defects [5]. In our geometry, we observe vortex rings detaching from the barrier and penetrating the cloud; since the vortices take energy from the flow, the superfluid current drops. This process is analog to the one observed in superfluid ^{4}He forced through a constriction [6]. We found that also the critical velocity for vortex nucleation is maximum on the crossover further confirming the superfluidity robustness for resonant atomic interactions [7].

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