Absence of a Dissipative Quantum Phase Transition in Josephson Junctions

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In 1962 Josephson predicted that an electric current can flow with no applied voltage through a thin insulating layer separating two superconductors. Since then, this "Josephson junction" has taken the central role in quantum electronic devices (squids magnetometers, parametric amplifiers, superconducting quantum processors,…). These devices have enabled testing many fundamental aspects of quantum mechanics to an exquisite degree of accuracy. Notably, the Josephson voltage standard opened the way to the rebasing of the International System of Units on quantum effects.

In spite of this success story, the interaction of a Josephson junction with a high-resistance electromagnetic environment was long misconceived and inconsistent. Specifically, in 1983, researchers predicted that when a Josephson junction is connected in series with a resistance greater than $h/4e^2 \simeq 6.5$ kΩ, a dissipative quantum phase transition should occur, with the junction becoming insulating as temperature is reduced to zero. This prediction was widely believed to be correct, even though it raised consistency issues with well-known simple limits cases.

We tested this prediction by connecting junctions to resistances of 8 and 12 kΩ and observed no trace of the predicted quantum phase transition. We propose a new theoretical analysis which accounts for our observation and resolves previous inconsistencies in the theory. This reveals subtle differences between this system and others, previously thought equivalent, in which a phase transition was confirmed.

References:

[1] Murani et al., Phys. Rev. X 10, 021003 (2020).

[2] Murani et al., Phys. Rev. X 11, 018002 (2021).