Towards a micromechanical qubit based on quantized oscillations in superfluid helium

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Superconducting circuits with Josephson junctions can exhibit quantized energy levels and long coherence times, which led to their successful deployment as qubits, quantum limited amplifiers and sensors. Superfluidity is in many respects the mechanical analogue of superconductivity with dissipationless mass flow. Josephson tunneling has been demonstrated in superfluid helium as well as in atomic and polariton condensates. In this work, we propose a hybrid quantum device, consisting of a superfluid weak link and a mechanical element. The oscillations of the superfluid in this device are quantized with a well-defined resonance frequency, resolvable at millikelvin temperatures essential to maintaining the superfluid state. Appropriate device engineering can yield the necessary nonlinearity to realize qubit functionality. Hence, this hybrid device can operate as a charge-neutral, superfluid quantum bit with micron-size dimensions and millisecond scale coherence times. We show that this quantum regime is within reach for a range of device designs. The scheme also provides a means to realise ground states of mechanical degrees of freedom.