Dark Soliton Qudits: A Novel Quantum Information Platform

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We study the possibility of using dark-solitons in quasi one-dimensional Bose-Einstein condensates to produce two or three-level systems (qudits) by exploiting the intrinsic nonlinear and the coherent nature of the matter waves. More precisely, we intend to create the dark soliton qudits by using trapped impurities. The decoherence induced by the quantum fluctuations (phonons) produces a finite lifetime due to their intrinsic slow-time dynamics. Remarkably, the qubit lifetime is estimated to be of the order of a few seconds, being only limited by the dark-soliton death due to quantum evaporation. Further, we explore the spontaneous generation of phononic entanglement between dark soliton qubits in the dissipative process of spontaneous emission. Moreover, we derive the analytical expression of the linear susceptibility to demonstrate the phenomenon of acoustic transparency based on matter wave phononics. The dark-soliton qutrit with unique properties of transmission and dispersion revealing the possibility of slowing down the speed of acoustic pulse. Our results suggest that dark-soliton qudits are a good candidates for quantum information protocols based purely on matter-wave phononics.