When quantum transport meets quantum optics

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Transport of elementary charge carriers across a dc voltage biased circuit usually does not couple to the electromagnetic modes embedded in the circuit. We consider here an opposite situation where these modes strongly couple to charge transfer: a voltage biased Josephson junction in series with a high impedance microwave resonator [1]. In this very simple quantum electrodynamics open system, the effective coupling constant that replaces the fine structure constant of QED is the ratio between the resonator characteristic impedance and the relevant resistance quantum Hofheinz et al., $R_Q = h/4e^2 \simeq 6.5$ kΩ . At coupling constant approaching one, the transfer of single Cooper pairs strongly couples to the resonator whose quantum state can be probed externally. We show that, in this strong coupling regime, the transfer of a single Cooper pair only occurs when its energy 2 eV can be transformed in $1, 2...n$ photonic excitations of the resonator. We also identify a recently predicted regime for which the presence of a single photon blocks the creation of a second one, which forces the resonator to emit a single photon in the external circuit before another Cooper pair can pass and re-excite it. Using a two-mode resonator circuit with different frequencies, we demonstrate a regime in which the transfer of a single Cooper pair simultaneously excites a single photonic excitation in each mode [2]. We find that the quantum state of the resonator violates a Cauchy inequality, which demonstrates its non-classical character.

[1] Hofheinz et al., Phys. Rev. Lett. 106, 217005 (2011)

[2] Westig et al., arXiv 1703.05009