Quantum engines via measurements on non-Markovian time scales

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The anomalies of work, heating or cooling induced by frequent perturbations of open quantum systems are intimately related to the little-explored quantum correlations (entanglement or discord) that arise between the system (e.g., a qubit) and a thermal bath because of their coupling. Such correlations, which have previously eluded attention, have been shown by us both theoretically [1-4] and experimentally [5] to profoundly change the dynamics of the bath and the system once we perturb the system within the bath-memory (non-Markovian) time scales. The required perturbations can either be effected by frequent projective measurements of the qubit energy, or by its frequent modulation (ultrafast driving), giving rise to novel, anomalous regimes: a) Quantum heat engines (QHE): We present a hitherto unexplored QHE design, based on anomalies that arise from frequent quantum nondemolition (QND) measurements or phase flips of a qubit in contact with a non-Markovian bath [1,4]. Either operation results in a non-equilibrium state that starts evolving and can close a cycle via qubit-modulation by a piston, e.g., a coherently-driven oscillator mode. An intriguing anticipated consequence of such QND operations is the ability to extract net work (from the qubit to the piston) using a single bath, although such operations do not acquire information that can be converted into work, as opposed to Maxwell's demon. This anomaly may appear to contradict the second law, but in fact it does not, once the measurement or phase-flip cost in energy and entropy is accounted for. b) Entanglement-based QHE: Two or more qubits coupled to the same bath mode have recently been predicted by us to be inevitably entangled via the bath [6]. This entanglement is expected to principally affect the QHE performance. c) Non-Markovian quantum refrigerator (QR): Ultrafast cooling (purification) of qubits, may be attained at non-Markovian time-scales by frequent quantum measurements or phase shifts [3,5]. It allows us to put forward a novel, highly-compact, QR design which consists of a single qubit simultaneously coupled to hot and cold non-Markovian baths. Phase flips of the qubit at high rates are shown to cause refrigeration: Heat may then flow from the cold to the hot bath via the qubit. The third law is upheld: under no circumstances can the bath refrigeration attain absolute zero.

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