Emergence of non-thermal statistics in isolated many-particle quantum systems after multiple perturbations

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We investigate what ensembles emerge dynamically in the course of strictly unitary manipulations of quantum systems. In particular, we look at the effects of multiple small non-adiabatic perturbations. This investigation is motivated by the following concerns. On the one hand, a typical quantum state of a large system constitutes a superposition of eigenstates that do not necessarily fall into the microcanonical energy window or represent any other conventional ensemble consistent with the Gibbs equilibrium for small subsystems. On the other hand, the linearity of quantum mechanics implies that the occupations of quantum eigenstates of isolated systems do not change with time. Therefore, if the statistical ensemble that emerges as a result of a given preparation routine is inconsistent with the requirements for the Gibbs equilibrium, then the system considered will never thermalize on it own. That the above concerns are not purely abstract is demonstrated by our recent work showing that, on the one hand, a certain natural ensemble called "Quantum Micro-Canonical" (QMC) ensemble leads to a non-thermal statistics[1], while, on the other hand, very similar ensembles were generated numerically by multiple small non-adiabatic perturbations acting of isolated clusters of spins 1/2 in a rather generic setting[2]. The QMC ensemble is defined for large but finite Hilbert spaces and admits all possible quantum superpositions with a given energy expectation value. In comparison with the conventional canonical ensemble, the QMC ensemble implies higher occupations for both very low- and very high-energy states and, correspondingly, lower occupations for the intermediate-energy states[1]. In our numerical investigations, we perturbed finite clusters of anisotropically coupled spins 1/2 by sudden pulses of external magnetic field[2]. Various sequences of magnetic field pulses were tried. In each run, a spin cluster was initially in a conventional thermal equilibrium. We have found that strictly periodic pulses lead to the dynamical localization of energy and the resulting the freezing of the time evolution of quantum ensembles. However a small randomization of the time delay between the pulses suppressed the above localization, and as a result the numerically generated statistical ensembles gradually departed from the canonical statistics and approached the QMC-like statistics. A possible implication of the above results is that isolated quantum systems having not too large number of particles but already large number of quantum levels might universally exhibit the non-thermal QMC-like statistics under multiple small perturbations. The implications of these results for macroscopic systems require further study.

[1] B. V. Fine, Phys. Rev. E 80, 051130 (2009).

[2] K. Ji and B. V. Fine (2011), arXiv:1102.3651 (accepted to Phys. Rev. Lett.)