Emergence of Classicality from Equilibration in Isolated Quantum Systems

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The emergence of macroscopic behavior is a central theme in both quantum mechanics and statistical physics. In the standard accounts, classicality and thermal equilibrium are typically explained by coupling the system to an external environment or bath: environmental interactions suppress interference (decoherence) and drive relaxation toward a thermal state. Over the last decades, however, a complementary perspective has emerged in which thermalization can occur even in fully isolated quantum systems evolving unitarily, in the operational sense that expectation values of relevant observables remain close to equilibrium values for most times. In this work we ask whether the same intrinsic equilibration mechanism can also account for the emergence of macroscopic classical behavior in quantum mechanics. Using bounds on equilibration in closed systems, we investigate conditions under which a time-evolved pure state is, for most times, indistinguishable (with respect some observables) from an appropriate classical mixture. This provides a route to an operational quantum-classical transition without invoking an explicit bath and suggests a direct link between two foundational questions: the origin of thermalization in closed quantum systems and the quantum-to-classical transition in macroscopic physics.

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