

Is Entanglement Necessary for the Typicality Argument in Statistical Mechanics?

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Typicality arguments replace the postulated mixed-state ensembles of statistical mechanics with pure states sampled uniformly at random, explaining why most microstates of large systems exhibit thermal behavior. This paradigm has been revived in quantum contexts, where entanglement is deemed essential, but no clear quantitative link between entanglement structure and typicality has been established. Here, we study pure quantum states with controlled multipartite entanglement and show that when entanglement grows with system size N , fluctuations in macroscopic observables decay exponentially with N , whereas if entanglement remains finite, one recovers only the classical $1/\sqrt{N}$ suppression. Our work thus provides a quantitative connection between entanglement structure and the emergence of typicality, demonstrating that entanglement is crucial for thermalization in small quantum systems but unnecessary to justify equilibrium in macroscopic ensembles. This unifies classical and quantum foundations of statistical mechanics by pinpointing exactly when—and why—entanglement matters

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