Experimental studies of dynamical tunneling in nuclear spin systems using NMR

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Tunneling is conventionally defined as the phenomenon in which a quantum system penetrates a potential barrier despite having lesser energy than the barrier height. Dynamical tunneling, on the other hand, describes the mechanism by which a quantum system accesses regions of the phase space that are isolated by its dynamics. This is observed in chaotic systems with mixed phase space comprising disconnected islands of regular regions surrounded by a sea of chaotic region. Classically, a system initialized in a regular region remains localized therein as the dynamics prohibits crossing over the chaotic sea and beyond. Quantum systems, however, can bypass this and exhibit periodic tunneling between the disconnected regular regions.

Here, we study dynamical tunneling of nuclear spins in NMR architecture using the quantum kicked top model, a quintessential model of chaos. We operate in the mixed phase space regime, and use the expectation values of the angular momentum operator as probes to observe tunneling of the quantum system between regular regions. The expectation values of these operators show periodic revival as the system tunnels between regular regions. We also study the dependence of the tunneling period on system size, and show that as the system size increases thereby approaching the classical limit, the period becomes longer, signalling suppression of tunneling behaviour. We further study quantum correlations such as von Neumann entropy and quantum discord during dynamical tunneling. These studies open avenues to explore tunneling in a generic chaotic environment, such as transport in a leaf or biological cell, qubits in a noisy quantum channel, many body quantum chaotic systems, etc.

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