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Open quantum systems approach in quantum field theory

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The standard paradigm of neutrino oscillations assumes that neutrinos propagate as a coherent superposition of mass eigenstates. However, in a number of physical scenarios — including wave packet spreading, quantum gravity effects, spacetime fluctuations, or interactions with a hot or dense medium — this coherence can be violated, leading to the phenomenon of neutrino decoherence. Decoherence manifests itself as an exponential damping of the interference terms in the oscillation probability and, consequently, can modify predictions for oscillation experiments. Searches for such effects are actively pursued using data from reactor experiments (KamLAND, Daya Bay, RENO) and accelerator experiments (MINOS/MINOS+, T2K, NOvA), and are also part of the physics programme of future facilities such as JUNO and DUNE. The theoretical description of decoherence naturally fits within the open quantum systems framework, where neutrinos are treated as a subsystem interacting with a quantum environment.

In this work, the open quantum systems formalism is applied to the dynamics of neutrinos in a thermal bath of bosons at finite temperature. Within the Markov and secular approximations, a reduced kinetic equation for the neutrino density matrix is derived from the von Neumann equation for the total "neutrino + environment" system, yielding a Lindblad-type master equation. It is shown that the resulting equation naturally unifies coherent and dissipative processes: the commutator term governs the unitary evolution, including corrections to the Hamiltonian, while the dissipative part describes incoherent processes associated with neutrino decay and its inverse process in the medium.

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