Revisiting the Fermi Golden Rule: Localization, Quantum Diffusion and Survival Collapse in Resonant States

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Nanosystems are never isolated, hence, the excitations have a survival probability $P_{00}(t)$ which typically decays with the Fermi Golden Rule (FGR) that neglects memory effects. Three surprising effects arise beyond these approximations.

1) Survival collapse due to Non-Markovian effects[1]. When an excitation of energy ε_o decays into the continuum spectrum of the environment whose dynamics is solvable, one finds the three dynamical regimes of the survival probability $P_{00}(t)$. **a)** The decay starts quadratic, as expected for a finite Hamiltonian second moment until a time proportional to the spectral density of the final states, as $t_S \simeq \hbar N_o(\varepsilon_o)$. **b)** Then the survival is described by a self-consistent Fermi Golden Rule (SC-FGR). **c)** At long-times $t >> t_R$ the pure survival probability is overrun by an inverse power law identified with the return probability at $t_R \approx \alpha(\hbar/\Gamma_o)ln[\beta B/\Gamma_o]$ where B is the bandwidth and $\alpha, \beta > 1$. At this last cross-over, $P_{00}(t)$ can drop several orders of magnitude. This survival collapse, last a brief period $\hbar/B$.

2) Quantum Coherence in spite of strong interactions. Decoherence appears as the progressive disappearance of interferences from the excitation under the action of an uncontrollable perturbation whose effectiveness is provided by chaos in the unperturbed system. An effective way to quantify decoherence is through the Loschmidt Echo, and the application of the FGR provides a tool to quantify this decay. We find that too fast fluctuations of the environment can lead to better coherence in the dynamics. This counter intuitive result is confirmed by experiments.

3) Quantum Dynamical Phase Transition. Decay is not always the only ingredient and one might need to consider the incoherent return of probability. We solve explicitly one of such cases using the Keldysh formalism. We found that a Dynamical Phase Transition can take place when Γ describing the interaction with the environment becomes of the order of $\delta\varepsilon$, the level spacing producing the dynamics. Beyond that value the dynamics becomes completely frozen through the Quantum Zeno Effect and the systems start a very slow relaxation to equilibrium. We present a detailed description of this effect and the experimental results showing the dynamical phase transition.

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