Can decoherence of a quantum system be suppressed by application of a strong electromagnetic field?

Summer Student Session

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Theory

The Hamiltonian

The dynamics of a **two-level system (TLS)** coupled to an environment and driven by an external field is described by

$$H(t) = \frac{1}{2}\varepsilon\sigma_z + \sum_a \frac{w_a}{2}\left(-\frac{\partial^2}{\partial Q_a^2} + Q_a^2\right) + \sum_a \lambda_a Q_a \sigma_x + E(t)\sigma_x$$

$\varepsilon = w_1 - w_2$ - energy gap of the TLS

$Q_a\,,\ w_a$ - coordinates and frequencies of environment

λ_a - coupling parameter

$E(t) = A(t)\cos(w_f t + \varphi_0)$ - strong periodic field

$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix},\quad \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ - Pauli matrices

The TLS's density matrix

From the solution of the time-dependent Schrodinger equation

$$i\frac{d\varphi(t)}{dt} = H\varphi(t)$$

we can calculate **the density matrix**

$$\rho_{\sigma\sigma'}(t) = \int d\mathbf{Q_a}\,\varphi^*(\sigma,\mathbf{Q_a},t)\,\varphi(\sigma',\mathbf{Q_a},t) \iff \begin{pmatrix}\rho_{00} & \rho_{01}\\ \rho_{10} & \rho_{11}\end{pmatrix}$$

and determine **the degree of coherence** of the TLS

$$c_{01} = \frac{|\rho_{01}|}{\sqrt{\rho_{00}\,\rho_{11}}}$$

$c_{01} \in [\,0\,;\,1\,]$ and $\to 1$ for a completely coherent state

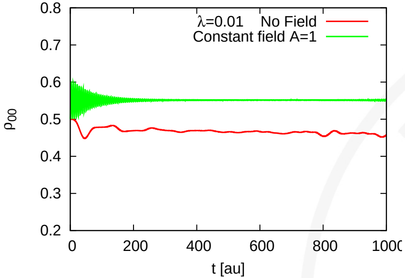
Results and Discussion

The TLS's time evolution

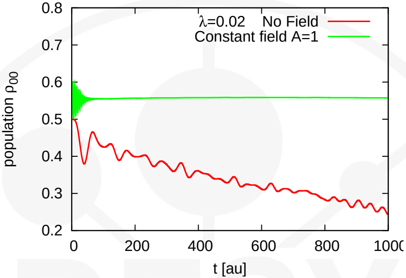
TLS + Environment + *Constant Field*

$w_{bath} < \varepsilon$

$\lambda = 0.01$



$\lambda = 0.02$

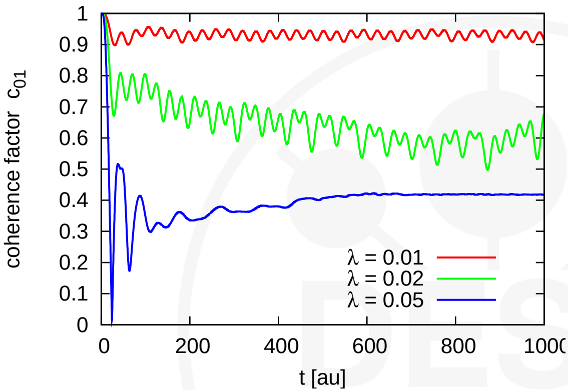


- The higher coupling parameter the faster transition of population
- In the presence of constant field population stabilizes

The degree of coherence

TLS + Environment

$w_{bath} < \varepsilon$



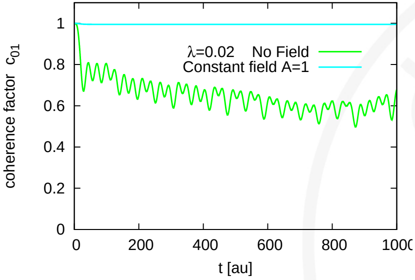
- The stronger coupling to environment the more decoherent system

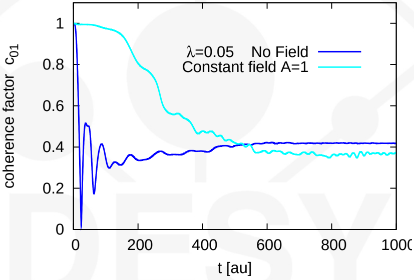
The degree of coherence

$$TLS + Environment + Constant\ \ Field$$

$$w_{bath} < \varepsilon$$

$\lambda = 0.02$ $\lambda = 0.05$





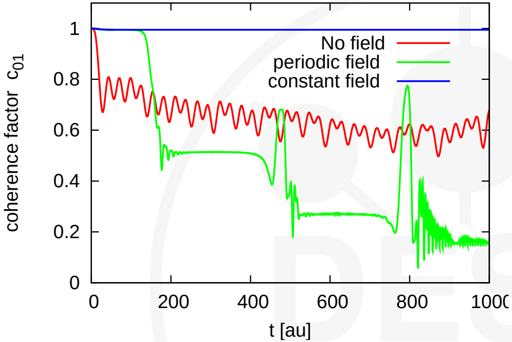
- The stronger coupling to environment the more difficult to suppress decoherence

The periodic field

$$TLS + Environment + Periodic\ Field$$

$$w_f < \varepsilon\ -\ nonresonant\ case$$

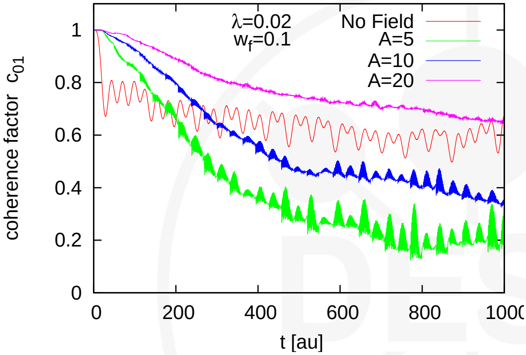
$$w_{bath} < \varepsilon\ ,\ \ \lambda = 0.02$$



- Every half-period field vanishes, we see only the effect of environment => the degree of coherence of the system falls

The periodic field

$$TLS + Environment + Periodic\ Field$$
$$w_f = \varepsilon\ \ - resonant\ case$$
$$w_{bath} < \varepsilon\ ,\ \ \lambda = 0.02$$

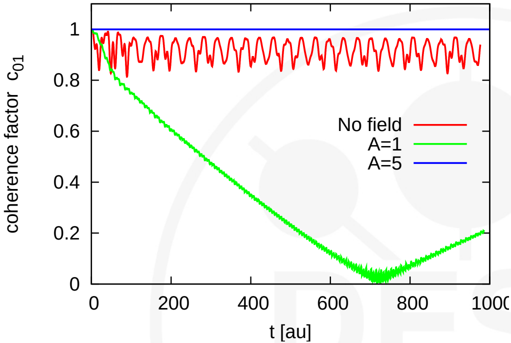


- The higher amplitude of the field the easier to suppress decoherence

On the other side

$TLS + Environment + Constant\ \ Field$

$w_{bath} > \varepsilon$



- The strong coupling to environment leads to a sharp decrease in coherence

Can decoherence of a quantum system be suppressed
by application of a strong electromagnetic field ?

Yes , can !

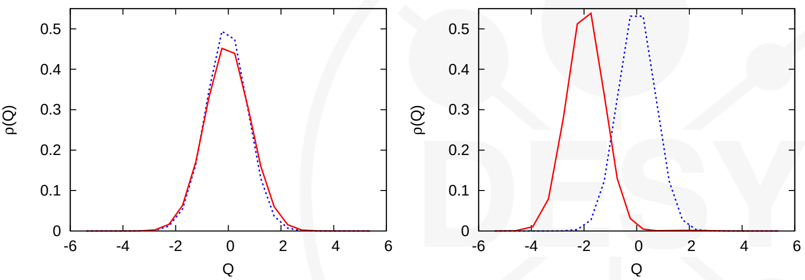
Appendix

The one-particle density matrix

The one-particle density matrix for each coordinate of bath

$$\rho(Q_1, t) = \sum_{\sigma=0,1} \int dQ_2 \ldots, dQ_{12}\, \varphi^*(\sigma, \mathbf{Q_a}, t)\, \varphi(\sigma, \mathbf{Q_a}, t)\,,\ a = \overline{1, 12}$$

gives us information about the bath evolution



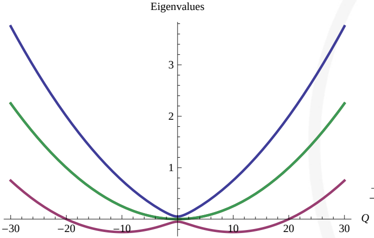
The external field drives the bath through the TLS

The eigenvalues

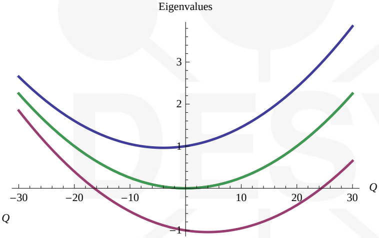
$$\begin{pmatrix} \frac{\varepsilon}{2} + \frac{w_1 Q_1^2}{2} & \lambda_1 Q_1 + E(t) \\ \lambda_1 Q_1 + E(t) & -\frac{\varepsilon}{2} + \frac{w_1 Q_1^2}{2} \end{pmatrix} \tilde{\varphi} = \tilde{\varepsilon}\tilde{\varphi}$$

The eigenvalues of driven TLS coupled to one bath harmonic oscillator

$$\tilde{\varepsilon}_{\pm} = \frac{1}{2}(w_1 Q_1^2) \pm \sqrt{\varepsilon^2 + 4(\lambda_1 Q_1 + E(t))^2}$$



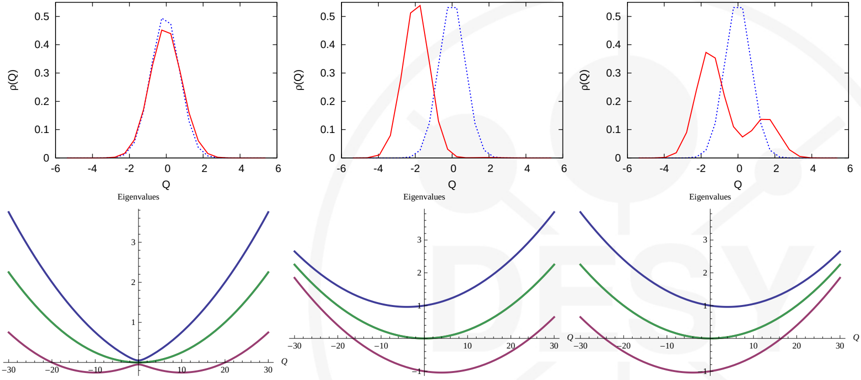
E(t)=0



E(t)=A=1

The one-particle density matrix

$$\tilde{\varepsilon}_{\pm} = \frac{1}{2}(w_1 Q_1^2) \pm \sqrt{\varepsilon^2 + 4(\lambda_1 Q_1 + A\cos w_f t)^2}$$



E(t)=0

E(t)=A=1

E(t)=A=-1