

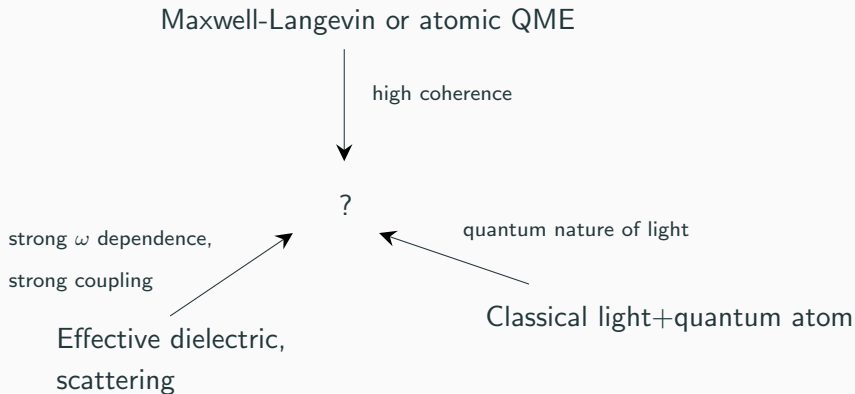
Cavity QED

Quantum light-matter interaction to the extreme

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April 13, 2024

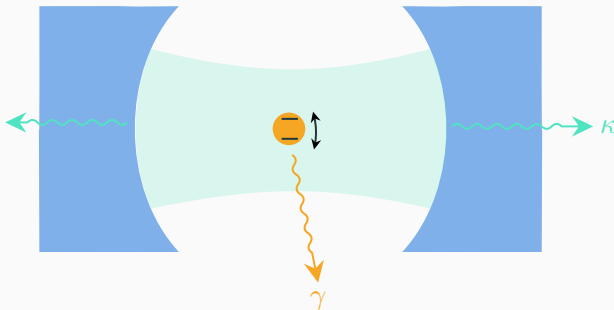
When do all effective theories of light or matter fail?



One scenario: in a cavity.

Cavity and one atom

Cavity quantum electrodynamics (cavity QED)



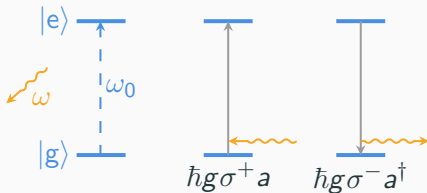
Coupling with the environment

- Cavity leaking κ
- Atomic spontaneous emission rate (outside the cavity) γ
- (Possible non-radiative decay: phonon, etc.)

Small $\kappa, \gamma, \dots \Rightarrow$ closed-system cavity QED

Jaynes-Cummings model

- No atom-atom interaction
- Rotating-wave approx.
- Single active photon mode
- No damping at all



$$H^{\text{Jaynes-Cummings}} = \hbar\omega \left(a^\dagger a + \frac{1}{2} \right) + \frac{\hbar\omega_0}{2} \sigma^z + \hbar g (a\sigma^+ + a^\dagger\sigma^-)$$

Possible coherent state driving $\omega_0 \rightarrow \Delta = \omega_0 - \omega_{\text{drive}}$

Quantum Rabi oscillation

Quantum nature of the model

- $|e\rangle \xrightarrow{\text{Spontaneous emission}} |g\rangle$ (but not irreversible)

Dressed state $H^{\text{Jaynes-Cummings}}$ in $\{|g, n+1\rangle, |e, n\rangle\} =$

$$\hbar\omega \left(n + \frac{1}{2}\right) - \frac{\hbar\omega_0}{2} + \begin{pmatrix} \hbar\omega & \hbar g\sqrt{n+1} \\ \hbar g\sqrt{n+1} & \hbar\omega_0 \end{pmatrix}$$

- Starting with $|e\rangle$
- Markovian approx. fails

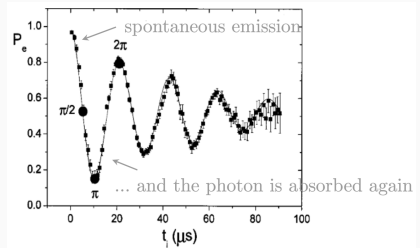


Fig. from S Haroche et al., RMP 73 565 (2001)

What happens when we start with $|e, \alpha\rangle$?

$$|\psi(t=0)\rangle = |e\rangle \otimes e^{-\frac{|\alpha|^2}{2}} \sum_{n=0}^{\infty} \frac{\alpha^n}{\sqrt{n!}}$$
$$\Rightarrow P_e(t) = \frac{1}{2} \left[1 + e^{-|\alpha|^2} \sum_{n=0}^{\infty} \frac{|\alpha|^{2n}}{n!} \cos(\Omega_n t) \right].$$

Generalizations

Medium

Medium within cavity?