**Introduction**

Dipole-dipole interactions between atoms give rise to fascinating applications in quantum information science like quantum logic operations or entanglement production. Those interactions modify the laser excitation of adjacent atoms such that it can be greatly suppressed, that is, the dipole blockade effect. Consider two two-level atoms exposed to a laser field of Rabi frequency $\Omega$. We give the interaction Hamiltonian

$$
H = \hbar \delta |e⟩⟨e| + \hbar \delta (e^{2\hbar \Omega} S^+_1 S^-_2 + e^{2\hbar \Omega} S^+_2 S^-_1 + \text{h.c.}).
$$

The time evolution of the system is governed by the master equation

$$
\dot{\rho} = -i[H, \rho] - \frac{\gamma}{2} \sum_{i=1}^2 \left( S^+_i \rho S^-_i + S^-_i \rho S^+_i - 2 S^+_i \rho S^+_i \right),
$$

where $\gamma$ is the total dissipation rate.

For a given state, we can probe the effects of the dipole blockade with the quantity $P_{ee}/P^+_e$ with

$$
P_{ee} = \langle e|\rho|e⟩.
$$

For independent atoms, we have $P_{ee}/P^+_e = 1$.

**Photon-Photon Correlations**

When the atoms reach an equilibrium, the system is in its steady-state. We found the analytical expression of that state, which allows us to check the atoms behavior very easily. We find

$$
P_{ee} = \frac{4\Omega t^2 + 4(4\Omega t^2 + \gamma^2)\gamma t^3}{(\gamma^4 + 4\Omega^2 t^4 + 2\Omega^2 \gamma^2 + \gamma^4)^{3/2}},
$$

with $\gamma = -(4 + 2\gamma t)$. That quantity is plotted below. We observe that for a small laser power, the blockade becomes very important as the interaction grows. For greater powers, the atoms tend to behave independently.

We can also compute the concurrence of the steady state analytically. We get

$$
\rho_{SS}^{(2)} = \frac{\gamma^2 V^2 (4\Omega t^2 + \gamma^2)\gamma t^3}{(\gamma^4 + 4\Omega^2 t^4 + 2\Omega^2 \gamma^2 + \gamma^4)^{3/2}}.
$$

The concurrence is plotted above. For a fixed laser power value, the concurrence grows with the interaction. We see that for a given interaction value, we can tune the laser intensity to maximize the entanglement. We find that there is always entanglement in the system if $0 < 4\Omega t^2 < \gamma^2$.

The photon-photon correlation function is defined as

$$
g^{(2)}(\tau_1, \tau_2; t + \tau) = \frac{P(\tau_2, t + \tau | \tau_1, t)}{P(\tau_2, t)}
$$

where $P(\tau_r, t)$ is the probability of detecting a photon at $r$ and $t$, and $P(\tau_2, t + \tau | \tau_1, t)$ the probability of finding another photon later at $\tau_2$ and $t + \tau$ after the first one was recorded. We plot that quantity below, for some disposition of the detectors. From the slope of $g^{(2)}(\tau)$ at small $\tau$, we observe an antibunching behavior in all cases, though stronger when the interaction is higher. For another particular configuration of the detectors we have

$$
g^{(2)}(\tau_1, 0; \tau_2, 0) = \frac{P_{ee}}{P^+_e} \rho_{SS}^{(2)},
$$

which gives us a direct measure of the dipole blockade.

**Conclusion**

We provide a model able to analyze quantitatively the dipole blockade effect on a two two-level atom system. We show that it is an efficient mechanism for the production of entanglement and tunable with the laser intensity. We observe that the dipole blockade can be lifted in strong driving conditions. Finally we show that for some detector positions, the photon-photon correlation function can continuously monitor the interaction between atoms, which provides an efficient tool in the analysis of dipole blockade [1].


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**Steady-State**

The letter 'e' appears twelve times.