Sign-definite coherence, coherent population trapping, frequency doubling, and lasing without inversion in open driven three-level $V$ and $\Lambda$ systems

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We explore open driven $V$ and $\Lambda$ three-level systems coupled to an environment with dynamics governed by the Lindblad master equation. We perform a transformation into superoperator space, which brings the Lindblad equation into a Schrödinger-like form, thus allowing us to obtain exact analytical solutions for the density matrices of the $V$ and $\Lambda$ systems in a closed form. We establish physical conditions under which coherent manipulation of these systems results in quasi-stationary dynamics, sign-definite coherence, coherent population trapping, electromagnetically induced transparency, and lasing without inversion. We show that the quasi-stationary dynamics and sign-definite coherence in a driven $\Lambda$ system can be obtained by matching the applied Rabi frequencies with the decay rate induced by the interaction with the environment. We find that the laser-induced Autler-Townes doublet splitting in a driven closed $\Lambda$ system transforms into a quadruplet in the presence of interaction with an environment. Finally, we demonstrate anomalous light propagation and continuous lasing without inversion for an open $V$ system driven by a continuous wave laser.

FIG. 1: Sketch of open driven three-level systems in (a) $\Lambda$ and (b) $V$ configurations. The initial state is prepared in the ground state $|\psi(t = 0)\rangle = |b\rangle$. The Rabi frequencies, $\Omega_p = d_{ab}E_p/\hbar$ and $\Omega_c = d_{ac}E_c/\hbar$ are expressed in terms of the dipole moments $d_{ab}$ and $d_{ac}$, and amplitudes of the applied electric fields $E_c$ and $E_p$. The environment-induced decay rates from the excited state $|a\rangle$ to $|b\rangle$ and $|c\rangle$ states are given by $\gamma_p$ and $\gamma_c$ respectively. The imaginary part of the susceptibilities, $\text{Im}[\chi(\nu)]$, as a function of detuning $\Delta$ and dimensionless time $\gamma t$ are shown for driven (c) $\Lambda$ and (d) $V$ systems. Vanishing susceptibility results in electromagnetically induced transparency and an extreme slowdown of the group velocity of light propagation.