Recent progress in coherent multidimensional optical spectroscopy revealed effects of quantum coherence coupled to population [1] leading to population oscillations as evidence of quantum transport. Their description requires reevaluation of the currently used methods and approximations. We identify couplings between coherences and populations as the noise-induced cross-terms in the master equation generated via Agarwal-Fano interference that have been shown earlier to enhance the quantum yield in a laser and photocell [2]. We investigated a broad range of typical parameter regimes, which may be applied to a variety of photosynthetic complexes. We demonstrate that quantum coherence may be induced in photosynthetic complexes under natural conditions of incoherent light from the sun. This demonstrates that a photosynthetic reaction center may be viewed as a biological quantum heat engine (QHE) that transforms high-energy thermal photon radiation into low entropy electron flux [3]. The efficiency of the engine depends on quantum effects.

FIG. 1. (A) Schematic of a laser QHE, (B) Scheme of the photocell QHE consisting of quantum dots sandwiched between $p$ and $n$ doped semiconductors pumped by hot photons at temperature $T_h$ (energy source, blue) and by cold photons at temperature $T_c$ (entropy sink, red). The laser emits photons (green) such that at threshold the laser photon energy and pump photon energy are related by Carnot efficiency. Open circuit voltage of the photocell and solar photon energy $\hbar\nu_a$ are also related by the Carnot factor. (C) The reaction center of Photosystem II. A solar photon absorbed by one of the coupled molecules $P_{D1}$, $P_{D2}$ promotes an electron to the excited state. Then the electron is transferred to the acceptor molecule $Acc_{D1}$ accompanied by phonon emission and afterwards contributes to the current across the "load". (D) Schematic of electronic states of atoms inside the cavity, quantum dot solar cell; or charge separation states in reaction center. (E). Same as D but lower upper level $a$ is replaced by two states $a_1$ and $a_2$, which can double the power of a QHE when there is coherence between these levels.