Accounting for system-bath correlations in the time-local homogeneous master equation for an open quantum system

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The solution to the long-standing statistical physics problem of the existence of the time-local completely closed (homogeneous) master equation for an open quantum system (like the Boltzmann and Lindblad equations) with the system-bath correlations is presented. The basic idea is the application of the special projection operator to the conventional time-convolutionless generalized master equation (TCL-GME) for an open quantum system with the irrelevant inhomogeneous initial condition term comprising the system-bath correlations, which exactly transforms this equation into homogeneous (completely closed) time-local equation, where the system-bath correlations are included into the kernel governing its evolution. The obtained equation is equivalent to the equation for the system reduced statistical operator $F_S(t)$. This equation resolves the problem of taking into account the system-bath correlations in the time-local master equation for $F_S(t)$ thereby avoiding the commonly used product system+bath initial state. For further applications, this equation is specialized for a weak system-bath interaction in the Born approximation. As an example, the Gibbs initial system+bath state, from which a system is driven by an external force, and a bath as a system of quantum harmonic oscillators (Boson field) is considered. The evolution over time of $F_S(t)$ for a system with discreet spectrum is calculated, which shows explicitly how a system-bath correlations influence the evolution process at any timescale. Remarkably, at the large timescale, the terms, caused by initial correlations, vanish, i.e., the system-bath correlations cease influencing the evolution process, and the master equation for $F_S(t)$ becomes of the Lindblad-like form, i.e., this equation follows from the von Neumann equation in the weak system-bath interaction case with no "randomness" (product state-like) approximation. As an example of a system with continuous spectrum, an electron interacting with a Boson field of oscillators is considered. The influence of initial correlation terms is calculated, and the vanishing of correlation terms at the large timescale is shown, which results in the emergence of the Boltzmann equation for an electron (polaron) with no standard product-like initial state assumption.