Strong Field Physics in Open Quantum Systems

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Any realistic physical systems are in contact with the environment. This is known as an open quantum system. In contrast, closed quantum systems are impractical, as creating a perfectly isolated system is practically impossible. Moreover, any system measurement inevitably involves information exchange with the environment, further making the system "open". Unlike closed quantum systems, which evolve according to unitary time evolution, characterizing the dynamics of open quantum systems is much more complex.

Dephasing is a crucial fundamental concept in an open quantum system because it describes the loss of coherence in quantum superpositions when interacting with the environment, distinguishing quantum systems from classical ones. Regardless of its importance, the dephasing effect in the ionization process has only been treated by a simple $1/T_2$ decay term in most theoretical descriptions, with T_2 known as the dephasing time. We establish first principle calculations where a fundamental mechanics – *dephasing ionization* is analyzed, where the ionization triggered by the dephasing effects. In particular, the dephasing is introduced *via* an external environment (heat bath). At the high-temperature limit, our model suggests that the dephasing time is inversely proportional to the heat bath temperature T and the coupling strength j_o *i.e.* $T_2 = \hbar/(2k_B T j_o \pi)$, where $\hbar$ is the plank constant and k_B is the Boltzmann constant.

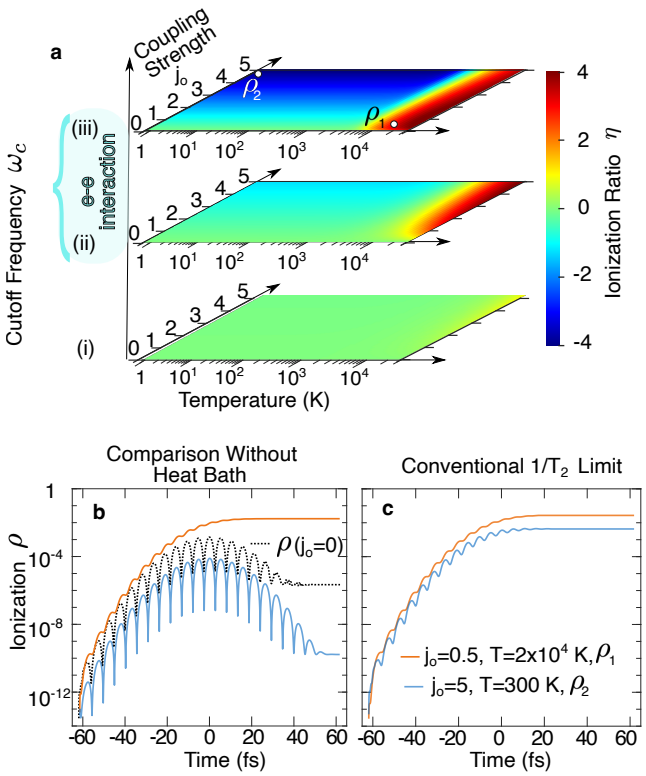

Figure 1: Panel **a** suggests the ionization ratio $\eta = \mathrm{Log}_{10}[\rho(t=\infty)/\rho(,t=\infty,j_o=0)]$ as a function of the temperature T and the coupling strength j_o, where $\rho(j_o=0)$ represents the ionization in the absence of the heat bath. Three cutoff frequency regimes are chosen which are (i) phonon, (ii) excition, and (iii) plasma. We choose 2 representative data points ρ_1 and ρ_2 in panel **a**. The time evolution of ρ_1 and ρ_2 in comparison without the heat bath case [black dashed curve] are presented in panel **b**. Panel **c** are obtained by the $1/T_2$ approximation whereas all the rest parameters are the same as panel **b**

Our results reveal that by coupling to the external heat bath, the ionization can increase/decrease up to 4 orders of magnitude ($10^{\pm 4}$) as shown in Fig. 1**a,b**. The comparison of results calculated by the $1/T_2$ limit is presented in Fig. 1**c**, where all the rest parameters are kept the same as Fig.1**b**. It is evident that the conventional $1/T_2$ limit largely overestimates the ionization by orders of magnitudes, especially at low temperatures. At high temperatures, the $1/T_2$ may remain a valid approximation.

Our results set the cornerstone for the fundamental understanding of ultrafast electron dynamics and provide an alternative for ionization manipulation. Our work has various foreseeable impacts. For example, by engineering the suppression of the ionization *via* a thermal environment, the damage threshold of the material can be largely enhanced. Consequently, the material can potentially tolerate stronger input electric fields, offering new adventures for strong-field light-matter interactions. In addition, the enhancement of ionization leads to orders of magnitudes stronger free electrons in the excited energy level, enhancing the ionization probability to even higher energy levels. This may open a door for X-ray physics and exotic topological phase studies.