Ultrafast excitation dynamics for noble gas atoms subject to intense femtosecond laser fields

S.P. Xu, [1] M.Q. Liu, [2] W. Quan, [1,3,]* W. Becker, [4] J. Chen, [5] & X.J. Liu [1]
*presenting author
[3]charlywing@wipm.ac.cn,
[1]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan 430071, China
[2] College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China
[4] Max-Born-Institut, Max-Born-Strasse 2a, 12489 Berlin, Germany
[5] Institute of Applied Physics and Computational Mathematics, P.O. Box 8009, Beijing 100088, China

S-matrix theory provides an efficient and physically appealing theoretical tool for the study of atomic and molecular dynamics in intense laser fields [1, 2]. For a given process, the S-matrix amplitude is usually expanded into the Born series. The series converges quickly only for a short-range or zero-range binding potential. If a long-range Coulomb potential has to be adopted to reproduce the experimental observations, e.g., the height of the plateau of high-order above-threshold ionization [3] or the low-energy structure [4,5], then the higher-order term may be larger than the lowest-order term and the convergence of the Born expansion becomes questionable.

Based on experimental data and theoretical analysis [6,7], we demonstrate that the second-order term of the S-matrix expansion may provide an effective theory for the intense-laser-atom interaction when the long-range Coulomb potential has to be adopted. Our work relies on experimental and theoretical investigations of ionization and Rydberg-state excitation of an argon atom subject to a strong laser field for various wavelengths. It is shown that the wavelength scaling law of the measured ratio of Ar* over Ar^+ and the period of its oscillation with respect to laser intensity can be well reproduced by the second-order term of the S-matrix expansion in terms of the Coulomb potential, but not by the lowest-order term. Our work sheds new light on establishing a comprehensive quantum theory for the atomic dynamics in strong laser fields.

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