The Magnus expansion for laser-matter interaction

Darko Dimitrovski*,[1], Morten Foerre†, Michael Klaiber‡, Lars B. Madsen* and John S. Briggs‡

*Lundbeck Foundation Theoretical Center for Quantum System Research, Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark
† Department of Physics and Technology, University of Bergen, 5007 Bergen, Norway
‡Theoretical Quantum Dynamics, University of Freiburg, Hermann-Herder Strasse 3 D-79104, Freiburg, Germany

Synopsis The interaction of an atom with a short, intense few-cycle pulse *including* nondipole effects is described by the Magnus expansion of the time-evolution operator. The time-evolution operator obtained in this approach is particularly simple involving position and momentum shifts of the laser field and the work done by the potential. The analytical Magnus expansion results agree excellently with numerical *ab initio* results.

The process of strong-field laser-matter interaction is highly nonlinear and, as such introduces theoretical and in particular computational challenges. However, at short wavelengths for atoms in their ground states or at ~ 800 nm for atoms in their low-lying Rydberg states the dynamics profoundly differs [1, 2]. In such cases, as we show here, a unitary approximation based on the Magnus expansion [3] of the time-evolution operator becomes appropriate.

In this contribution we

- give a recipe for the calculation of transition probabilities based on a systematic application of the Magnus expansion in powers of the pulse duration in dipole approximation and including nondipole effects,
- formulate the Magnus expansion for the calculation of *time-resolved* transition probabilities under the action of short laser pulses in dipole approximation, and
- set the limits of applicability and establish the connection of this approach to existing theoretical methods.

The main result is an analytic approximation to the time-evolution operator,

$$U(T,0) \approx U_0(T,T/2)e^{-iD(T)}e^{-iN(T)}U_0(T/2,0),$$

with T pulse duration, $U_0(t,t') = \exp(-iH_0(t-t'))$, $D(T)$ is operator summarizing dipole effects and $N(T)$ includes the nondipole effects. The operator $D(T)$ depends on the laser pulse type [1] and $N(t)$ amounts to shifting of the wavefunction in the propagation direction irrespective of the pulse type (see Fig. 1) [2].

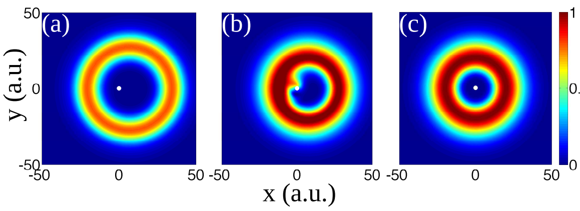

Fig. 1. Electron density in the $z = 0$ plane.; (a) obtained numerically; (b) obtained by backpropagating (a) in the field-free Hamiltonian for half pulse duration; (c) of the initial state $|n = 5, l = 4, m = 4\rangle$. The laser pulse at 400 nm propagates in x- and is polarized in z-direction (from [2]).

This analytic theory, easily extendable to a many-electron case, paves the way for controllable dipole- and nondipole-induced wavepacket shifting including ultrafast population transfer.

References

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[1]E-mail: darkod@phys.au.dk