Evolution operator technique for strong field atomic ionization with separable potential model

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Synopsis The direct use of the evolution operator for calculation of wave function and transition probabilities in laser- atom ionization with separable potential model is proposed. The method is applied to a simple 1D model supporting a finite number of bound states. Fast and reliable results are obtained.

The use of separable potentials that represent non-local potentials is a well known method for calculating scattering cross sections in time independent nuclear reactions [1]. More recently, separable potentials have been introduced for time dependent processes as a model to simplify the analysis of atomic ionization by strong laser fields [2].

Irrespective of either momentum or coordinate representations, the target potential is replaced by a separable potential with the general form:

$$V_{T,s} = \sum_{m,n} c_{mn} \left|m\right\rangle V_T \left\langle n\right|$$

where $c_{m,n}$ has to fulfill the required properties to keep $V_{T,s}$ as an hermitian operator. Thus target atom in the laser field Hamiltonian is in the velocity-gauge:

$$H = \frac{(\mathbf{p}+\mathbf{A}(t)\cdot\mathbf{p})^2}{2} + V_{T,s} = H_V(\mathbf{p},t) + V_{T,s}$$

where $\mathbf{p}$ is the momentum operator, and $\mathbf{A}(t)$, the vector potential operator (here $c \to 1$).

Within the separable potential model, the time-dependent Schrö dinger equation (TDSE) corresponding to this Hamiltonian is solved in terms of time dependent magnitudes that are obtained from a Volterra integral equation system. The kernels in this system are obtained in closed form for the Hydrogen case. Obtaining the kernels might represent a major task when the system is not longer Hydrogen atom.

In order to overcome this difficulty as well as to increase dramatically the number of states involved in the separable potential, the use of the propagator with the splitting-operator technique is proposed:

$$|\Phi(t+\Delta t)\rangle = e^{-iH_V(\mathbf{p},t)\Delta t/2} e^{-iV_{T,s}\Delta t} e^{-iH_V(\mathbf{p},t)\Delta t/2} |\Phi(t)\rangle$$

In the momentum space, the first and the last propagators are simple multiplication by a momentum dependent phase . The propagator in the middle reduces to a finite dimensional closed expression owing to the projector like properties of the separable potential.

In order to test this method, 1D atom model with Poschl-Teller potentials supporting a few bound-states is analyzed. In the present case, the target potential is $V_T = -\frac{\lambda(\lambda+1)}{2\cosh x^2}$ with $\lambda = 2.25$ supporting three bound states with energies $\varepsilon_0 = -2.53$, $\varepsilon_0 = -0.78$ and, $\varepsilon_2 = -0.03$ a.u.. The vector potential is given by $A(t) = A_0 \sin\omega t$ with $A_0 = 0.75$ and the laser frequency $\omega = 0.875$ a.u., corresponding to a two-photon resonance. The pulse duration is ten cycles. In Figure 1, the ionization probabilities with the three bound-states in the separable potential, as a function of time are shown. A sort of periodic pattern with increasing maxima is observede. Ionization probability rises as the electric field shifts the wave function. Under field reversion the shift reduces and ionization probability falls down to a large extent, but not to zero.

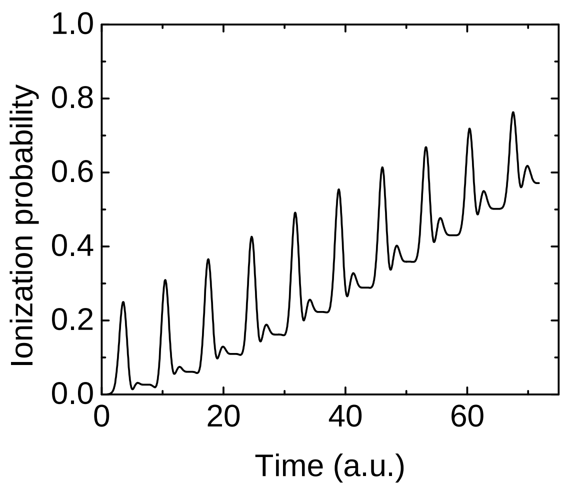

Figure 1. Model atom ionization probabilities as a function of time.

References

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