Transitions between Rydberg states induced by short electric pulse

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Two methods of transition probability calculations between Rydberg states induced by a short electric pulse are compared. The first approach of transition probability analysis is based on the action function, the other is based on the Wigner function.

Transitions between Rydberg states of atoms and ions are of great interest for both the quantum theory and for applied kinetic and diagnostic tasks. Atoms and ions in Rydberg states are quantum objects with nearly classical properties. Therefore, it is possible to apply the solution of classical motion equations to the quantum problem of transition probability. Our main aim is the investigation of the possibilities of the classical numerical methods for quantum problem. We consider this problem as a test of the various approaches to the general problem of the interpretation of the classical solutions in terms of the quantum problem.

The action increment method is based on the semiclassical approximation for the atomic wave function according to which the probability $\alpha' \leftarrow \alpha$ of transition is given by [1, 2] :

$$W_{\alpha'\alpha} = \left| \frac{1}{(2\pi)^3} \int_0^{2\pi} d\mathbf{u} \exp\left\{ -i \left[\mathbf{k}\mathbf{u} - \frac{eEz\Delta t}{\hbar} \right] \right\} \right|^2 , \tag{1}$$

where $k = \alpha - \alpha'$ vector denotes three dimensional difference of the quantum numbers $\mathbf{k} = (n - n', l - l', m - m')$, while $\alpha = (n, l, m)$ and $\alpha' = (n', l', m')$ are sets of Rydberg quantum numbers of the initial and final states, respectively; $\mathbf{u}$ (u_1, u_2, u_3) is the set of the conjugate action variables, z is the coordinate of the electron, e is its charge, E is electric field, Δt is duration of the electric pulse.

The Wigner function method is based on the fact that in the case of classical limit $\hbar \to 0$ Wigner function becomes the classical distribution function w. The main suggestion is that in the case of Rydberg states this distribution can be interpreted as Wigner function after the interaction. Averaging over final phases one can obtain the expression for the transition probability [2]:

$$W_{\alpha'\alpha} = \int d^3 I_n \prod_{n=1}^{n=3} \left[\frac{\sin(\pi q_n/\hbar)}{(\pi q_n/\hbar)} \right]^2 \tilde{w}_i (I_1, I_2, I_3) , \tag{2}$$

where $(I_1', I_2', I_3') = (n'\hbar, l'\hbar, m'\hbar)$ correspond to the final unperturbed state, and $\tilde{w}_i$ is the classical distribution function resulted after interaction from the initial state. The values $q_n = (I_n' - I_n)/\hbar$ define the difference between quantum numbers of the final state and the action in $\hbar$ -units calculated as the result of the integration along the classical trajectory. The factors

$[\sin(\pi q_n)/(\pi q_n)]^2$ give the relative probability of the contribution of the considered trajectory to the quantum state.

The results of both methods are close to each other in the region of medium and high action increments. The method of the interpretation of the numerical results of the classical problem in terms of the quantum mechanics based on the Wigner function can be perspective for the processes with the large action increment.

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[1] I.L.Beigman , V.S.Lebedev *Physics of Highly Excited Atoms and Ions* (Springer-Verlag, 1998).
[2] I.L.Beigman , S.A.Chernyagin *Phys. Scr.* submitted.