International Journal of Mathematical Archive-3(7), 2012, 2631-2633
IJMA Available online through www.ijma.info ISSN 2229 – 5046

DIPOLE and NONDIPOLE APPROXIMATION FOR DIPOLE EXCITATION OF HYDROGEN ATOM BY INTENSE ATTOSECOND LASER FIELD

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(Received on: 05-07-12; Accepted on: 25-07-12)

ABSTRACT

Validity of the dipole approximations for the excitation of the hydrogen atom by attosecond strong laser pulse is verified in the first order perturbation approximations. Our calculation show that the simple dipole approximations give the same results for the final value of the dipole transition probabilities as the more complicated nondipole calculations even when the pulse size is less than characteristic atomic size (n_f > 3) where the dipole approximation is invalid.

Key words: *Attosecond pulse, dipole approximation, lenght gauge, velocity gauge.*

I. INTRODUCTION

Excitation and ionization of atoms by attosecond laser pulse is had been studied theoretically in the strong field approximation[1] and also in the time dependent perturbation approximation[2]. In [2,5], the interaction of a hydrogen atom with an ultrashort laser pulse is considered for the case where the pulse size in the propagation direction is of the same order or less than the characteristic size of the initially occupied state.

In this paper, we consider the validity of the dipole approximations for the excitation of the hydrogen atom by attosecond strong laser pulse. Atomic units are used everywhere.

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II.THEORY

Consider the hydrogen atom in the strong field of the traveling attosecond laser pulse. We set the origin of the coordinate system at the nucleus. The electromagnetic pulse propagation was chosen along the *x* axis and the linearly polarized laser pulse electric field is along the z-axis:

$$\boldsymbol{E}(t,x)=\begin{cases}\hat{z}E_0\cos^2\left(\dfrac{(t-\alpha\cdot x)\cdot\pi}{\tau}\right)\sin\left(\omega\cdot(t-\alpha\cdot x)+\phi\right) if \quad |t-\alpha\cdot x|\le\dfrac{\tau}{2}\\ 0 \qquad otherwise\end{cases} \tag{1}$$

where E_0 is the amplitude of the electric field vector, and ω -carrier frequency ϕ -phase of the carrier, *c*-speed of light, τ - pulse duration respectively.

The atomic transition amplitude from initial to final state due to laser pulse interaction is determined to be [3]

$$a_{fi}=-\int_{-\infty}^{t}V_{fi}(t)\cdot e^{i\omega_{fi}t}dt \tag{2}$$

$V_{fi}(t)=\left\langle f\left|\hat{V}(t)\right|i\right\rangle$ - transition matrix element, $\hat{V}(t)$ -laser-atomic interaction, $\omega_{fi}=\varepsilon_f-\varepsilon_i$ transition angular frequency, and quantum numbers n_i,l_i,m_i and n_f,l_f,m_f are corresponds to initial and final atomic states respectively. The laser atom interaction in the dipole approximation and in the velocity gauge determined as:

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$$\hat{V}(t) = \hat{\boldsymbol{p}} \cdot \boldsymbol{A}(t) \qquad (3)$$

where $\hat{\boldsymbol{p}}$ is the momentum operator, $\boldsymbol{A}(t)$ is vector potential of the electromagnetic field.

In the length gauge the interaction can be written as:

$$\hat{V}(t) = \boldsymbol{r} \cdot \boldsymbol{E}(t) \qquad (4)$$

III. RESULTS AND DISCUSSIONS

Our choice of the pulse length is 27 a.u. and the pulse duration is 0.2 a.u., E_0=1. The transition probabilities of the ns-6p0 transitions are shown in Figures 1-3. As we can see from figure 1, the time evolution of the transition probability is restricted by the pulse duration. At the and of this time all the probabilities have very close values[6,7]. From the Figure 2, the probabilities in the velocity gauge differs from the probabilities in the length gauge only in the pulse duration region and equal to them in the final plateau region.

The dipole approximations will be compared with the 'exact' nondipole calculations shown in Figure 3, which takes into account the space variation of the pulse as in (1). From this figure one concluded that, the evolution time is defined by not only the pulse duration, but also the atomic initial state size: the longest evolution time corresponds to the largest (6s) atomic size [8].

The probability values in the plateau region in all three approximations the same except the 6s-6p0 transition which is zero in the length gauge (Table 1).

Our calculation show that the simple dipole approximations give the same results for the final value of the dipole transition probabilities as the more complicated nondipole calculations even when the pulse size is less than characteristic atomic size ($n_f > 3$) where the dipole approximation is invalid.

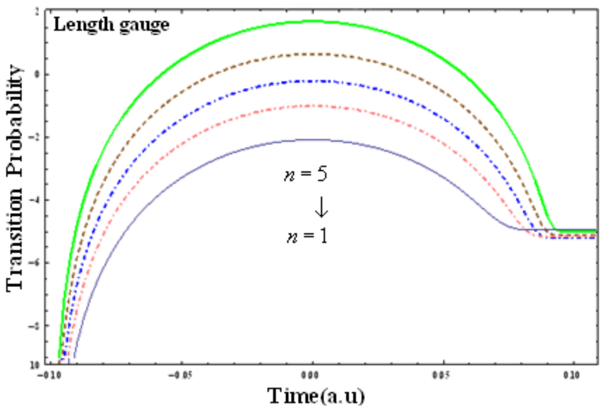

Figure 1. Time dependence of transition probability

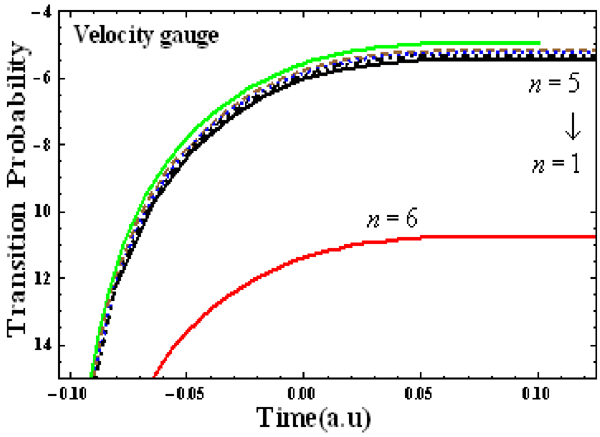

Figure 2.Time dependence of the transition probability.

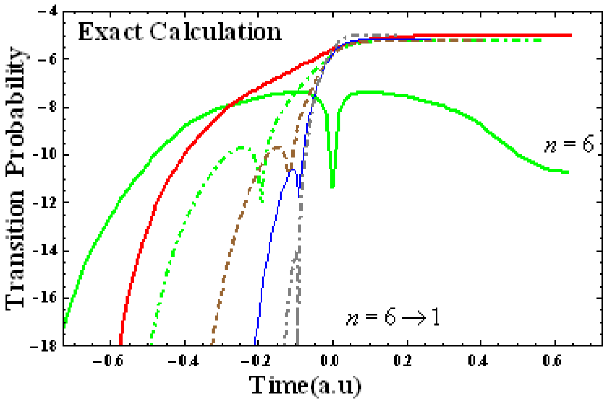

Figure 3. Time dependence of transition probability

Table 1.

Transition	Presice calculation	Dipole approximation	
		Lenght gauge	Velocity gauge
1s-6p0	-4.97186	-4.9613	-4.97177
2s-6p0	-5.17104	-5.18854	-5.17909
3s-6p0	-4.9636	-4.96413	-4.97177
4s-6p0	-4.99698	-5.11791	-4.98286
5s-6p0	-4.99698	-4.9887	-4.98286
6s-6p0	-10.7792	0	-10.7823

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Source of support: Nil, Conflict of interest: None Declared