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Stabilization of ionization due to two color laser fields

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Abstract. We examine the excitation dynamics of a model atom excited by a two commensurate (the fundamental and second harmonic) intense laser fields. We investigate that one can easily stabilize the quantum wave packet through suppression of photodetachment by changing the laser intensity and the relative phase between the two colors.

Keywords. Stabilization; ionization; two-colour; wave packet.

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Recent theoretical studies showed that atoms under a very strong high frequency field will be relatively very stable against ionization [1]. But the predicted frequency leading to ionization is much higher than the ionization potential [2], This kind of laser intensity required for stabilization [3–6], for systems in atomic ground state is not currently available in laser sources.

The study of atomic and molecular multiphoton processes in two strong laser fields has received considerable attention both experimentally [7] and theoretically [8–9], in recent years. An unexpected development in this study was the prediction of stabilization of any atom by a strong laser field. Stabilization means that the ionization rate becomes a decreasing function of the laser intensity. Work has been presented on stabilization of population in Rydberg levels and stabilization of atoms in the ground state [13] in quantum mechanical theories. Discussions of stabilization based on classical Newtonian equations have also been presented [12]. Also, in case of atoms, mostly two color studies have been confined to the investigation of phase dependence effects in multiphoton ATI. It has been found, for example, that the angular distribution depends strongly on the relative intensity and relative phase of the two radiation fields, usually consisting of a fundamental and one of its harmonic fields. Photodissociation of HD^+ is found to control by two color field [10].

The evolution of the system is studied by solving the Schrödinger equation (in a.u).

$$i\frac{\partial}{\partial t}\psi(x,t) = \Big(H_0(x) + H_L(x,t)\Big)\psi(x,t), \tag{1}$$

where,

$$H_0(x) = \frac{p^2}{2} + V(x) \tag{2}$$

is the unperturbed part of the Hamiltonian and $H_L(x,t)$ describes the laser-atom interaction term. We adopt a one-dimensional short range potential [5] of a negative ion to provide the binding of the outer electron to the atomic core,

$$V(x) = -24.856 \exp\left[\frac{-\sqrt{x^2+16}}{\sqrt{x^2+(6.27)^2}}\right]. \tag{3}$$

This screened coulomb potential has one bound state at a binding energy of 0.0278 a.u ($\sim$ 0.75eV) corresponding to known value of H^-.

The initial wave packet is taken to have a gaussian shape

$$\psi(x,0) = (\pi)^{-1/2} \exp\left(\frac{-x^2}{2(\Delta x_0)^2}\right), \tag{4}$$

with $\Delta x_0 = 5.1$ a.u corresponds to bound state wave function of H^- ion. This gaussian approximation and the true bound state has an overlap of more than 99% [5].

The laser-atom interaction in (1) is given by

$$H_L(x,t) = -E_0 F(t)[\sin(\omega t) + \sin(2\omega t + \phi)]x \tag{5}$$

where $|E_0|$ is the amplitude of the field and ϕ the phase difference between the fields. The $F(t)$ is envelope function chosen to be of gaussian form as,

$$F(t) = \exp\left[-\frac{[4(t-t_0)]^2}{\tau^2}\right]. \tag{6}$$

Thus, (1) can be written in more general form as,

$$i\frac{\partial\psi(x,t)}{\partial t} = H\psi(x,t) + S(x,t)\psi(x,t), \tag{7}$$

where $S(x,t)$ involves the laser-atom interaction. This equation can be solved numerically by unitary form of standard Crank–Nicholson algorithm based on finite difference approach.

The probability of photodetachment P_i with time using the completeness of the bound and continuum functions can be given as,

$$P_i(t) = 1 - \sum_n |\langle\phi_n|\ \psi(x,t)\rangle|^2. \tag{8}$$

In figure 1, we have shown the variation of ionization probability $P_i(t)$ with time for different field strengths for constant phase difference between the two colors. Here we find that with increase of field from E_0 = 0.40 a.u to 2.0 a.u the ionization probability decreases resulting in stabilization with increase of field. The effect of suppression of ionization is related to the destructive quantum interference of the amplitudes for transition to continuum from a closely spaced quantum state. In our case, since the system has single bound state, thus the ion can be stabilized by destructive interference.

Also, the other possible reason can also be, the formation of an electron wave packet oscillating with a large amplitude in the external electric field, and thus weakly interacting

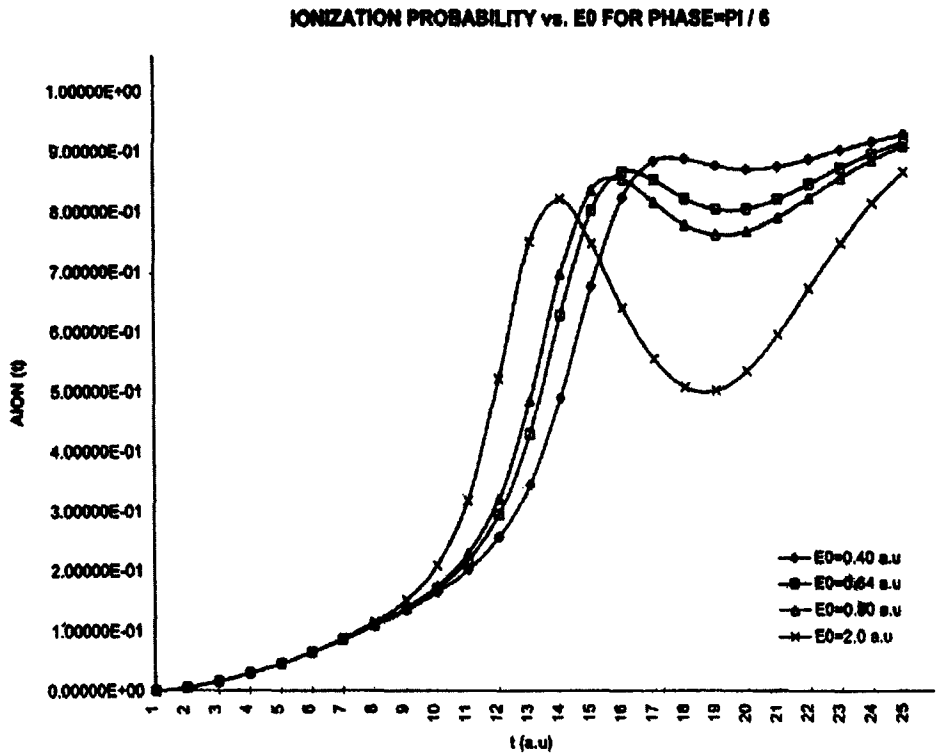

Figure 1. Variation of photodetachment probability $P_i(t)$ with time for $|E_0| = 0.40, 0.64, 0.80$ and 2.0 a.u. Here $\phi = \pi/6$ and $\omega = 0.0628$ a.u. Series 1,2,3,4 specifies $E_0 = 0.40, 0.64, 0.80$ and 2.0 a.u.

with the core, which reduces the chances of photon absorption. This increase in amplitude, is given by, $a_e = (eE_0/m\omega^2)$ of the electron oscillations in the field of the electromagnetic wave to values much larger than the range of the potential, as a result photon absorption becomes unlikely.

We also studied the effect of the phase on the ionization process. It can be seen from figure 2 that the ionization yield can be enhanced by varying the phase from $\pi/6$ to $\pi/2$ and decrease for $\phi = \pi$. We can thus alter the shape of the wave packet drastically. The degree of stabilization during and at the end of the pulse depends on the relative phase ϕ. It has been seen that changing the phase for high intensity, leads to maximal amount of stabilization (i.e. lower extrema of envelope) and is greatest for $\phi = \pi$.

We also studied the photodetachment process, and found out that for short range potential where the electron wave function is approximated as oscillating free wave packet spreading in space, for sufficiently long laser interaction time, the localized electron density approaches the amplitude of the free electron oscillation in the electromagnetic wave field. The atomic potential comes into picture and influences the trapping, localization and dichotomy processes, unlike given by [11] where the effect of the atomic well potential on the evolution of the wave function is slight.

In conclusion, one can control the stabilization and photodetachment rate by varying the intensity and the relative phase between the two-color laser radiation. We remark that it

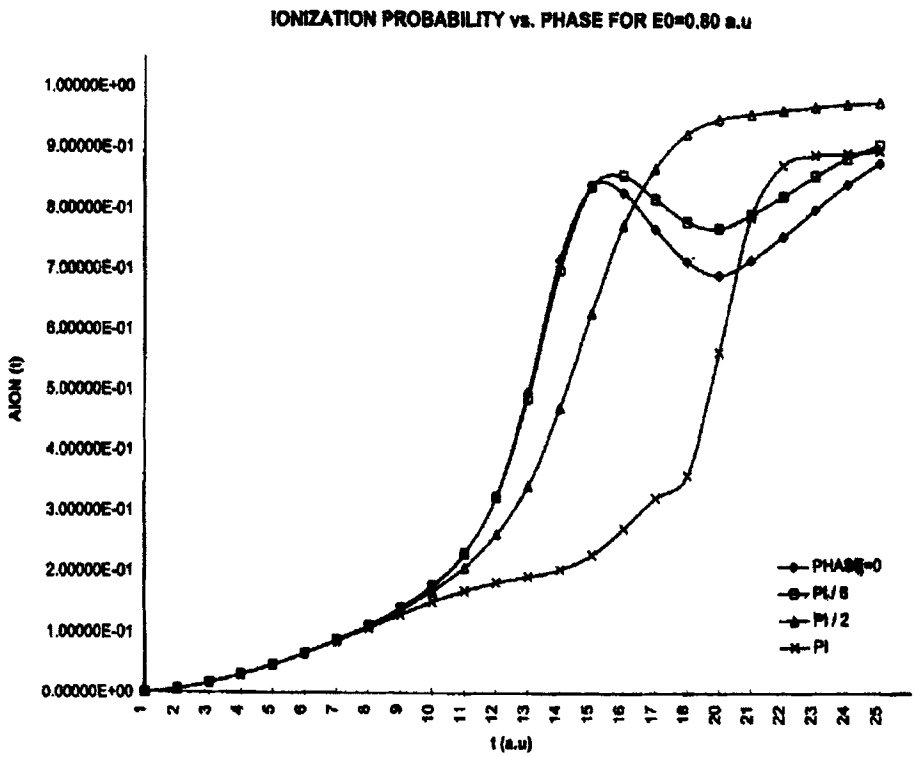

Figure 2. Variation of $P_i(t)$ with time for different phases, $\phi = 0, \pi/6, \pi/2$ and π. Here $|E_0|$ = 0.80 a.u. Series 1,2,3,4 specifies phase difference ϕ in ascending order.

is considerably easier in experiments to observe the stabilization of $-$ve ions than atoms in ultraintense fields. The optimum laser intensities in the visible wave band are equal to 10^{14}–10^{15} W/cm^2. Such laser parameters are close to those currently attainable and encourage us to believe that experiments on this will be performed in near future due to its useful applications in semiconductor physics, etc.

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