Non-constant ponderomotive energy in above threshold ionization by intense few-cycle laser pulses

Renata Della Picca*, Ana A. Gramajo*, Diego G. Arbó†, Sebastián D. López† and Carlos R. Garibotti*

*CONICET and Centro Atómico Bariloche, Av. Bustillo 9500, 8400 Bariloche, Argentina
†Instituto de Astronomía y Física del Espacio IAFE (Conicet-UBA), Casilla de Correo 67 Suc. 28, C1428ZAA Ciudad Autónoma de Buenos Aires, Argentina

Synopsis We analyze the above threshold ionization of hydrogen atom by strong and short laser pulse with a simple envelope temporal dependence. We find additional peaks in the resulting ATI spectra originated from different values of the ponderomotive energy and the interference due to the electronic emission at different times.

Since the first observation in the eighties [1], Above Threshold Ionization (ATI) process has been extensively studied in the context of strong laser-matter interaction. In this process the target absorbs more photons than the minimum number required for ionization. As a result, the photo-electron (PE) spectra are characterized by peaks at energy values given by energy conservation [2]:

\[ E = n\hbar \omega - I_p - U_p \]  

(1)

where \( \omega \) is the laser frequency and \( I_p \) is the ionization potential.

The ponderomotive energy \( U_p \) is the cycle averaged kinetic energy of an electron in an oscillating field. It is know that \( U_p = (F_0/2\omega)^2 \) when the electric field is described by a plane wave with amplitude \( F_0 \) [2]. However, the concept of \( U_p \) is questionable for few-cycle laser pulse. In this case, the field is commonly described as \( F(t) = f(t)F_0\cos(\omega t + \varphi) \) where the envelope \( f(t) \) takes values starting from 0 and increasing to the maximum value 1, tipically at the middle of the pulse duration. Hence, different values of \( U_p \) are expected for each cycle and then, following Eq. (1), different energy position in the ionization spectra [3].

In this work, in order to analyze the envelope effect on the PE spectrum, we consider primarily a very simple and didactic envelope function with few steps. The calculations were done for ionization of the hydrogen atom from 1s within the semi classical Simple Man’s Model (and also corroborated with the Coulomb-Volkov approach).

As we can see from the figure 1, each level of the field produces ATI peaks according to Eq. (1); and when another delayed step of same level is added, see figure 1 (b), the electrons emitted at different times generate a typical interference pattern in the PE spectrum [4].

During the conference we will show that this simple analysis can be easily extended to more realistic envelopes, as for example \( f(t) = \sin^2(\pi t/\tau) \) case.

**Figure 1.** H(1s) ATI PE spectra with \( F_0 = \omega = 0.25 \text{ a.u.} \) and 24 cycles. See insets for two envelopes: (a) one step and (b) symmetrical two steps.

**References**

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1E-mail: renata@cab.cnea.gov.ar