Eikonal approximation for above-threshold ionization

M. Yu. Kuchiev[1] and V. N. Ostrovsky[2]

[1] *School of Physics, University of New South Wales, Sydney 2052, Australia*
[2] *Institute of Physics, The University of St Petersburg, 198904 St.Petersburg, Russia;*
Electronic address: Valentin.Ostrovsky@pobox.spbu.ru

The standard Keldysh approximation for laser-induced ionization discards interaction of receding photoelectron with the atomic core. It becomes insufficient for photoionization of neutral atoms where Coulomb forces are operative between the active electron and residual core. This interaction was taken into account first by Perelomov *et al* [1] in the *quasistatic* limit of small laser frequency ω. A remarkably simple relation was obtained between the photoionization rate $w_{\rm C}$ for the electron initially bound by the Coulomb potential with the core charge Z and its counterpart $w_{\rm sr}$ for the electron with the same binding energy $E_b = \frac{1}{2}\kappa^2$, but bound by the short-range forces:

$$w_{\rm C} = \left(\frac{2\kappa^2}{F}\right)^{2Z/\kappa} w_{\rm sr} \ , \tag{1}$$

where F is the electric field strength in a laser wave. Eq. (1) means that in conventional conditions the presence of the Coulomb field enhances the rates by several orders of magnitude. More elaborate theory by Perelomov and Popov [2] showed that in fact relation (1), quite unexpectedly, holds both in tunneling and multiphoton regimes. It reproduces well experimental data for *total* ionization rates [3].

However the theory by Perelomov and Popov [2] is restricted to ejection of photoelectron with negligibly small translational momentum $\mathbf{p}$. Probably sometimes implicitly, it is anticipated that namely these photoelectrons give principal contribution to the total rates summed over all above-threshold ionization (ATI) channels as well as over ejection angles. The current experiments are able to select for study an individual ATI channel even for quite a large number of absorbed photons. Both energy and angular distributions of these electrons manifest some fascinating features which are object of acute interest in experiment and theory nowadays.

We develop the eikonal approximation to account for the Coulomb interaction between receding photoelectron and core within general framework of Keldysh-type theory of multiphoton ionization. The unperturbed classical trajectories correspond to wiggling electron motion in the laser wave whereas the effect of the Coulomb field results in an additional gain of phase along these trajectories. In contrast to previous treatments the photoelectron momentum is not presumed to be small. This allows us to evaluate angle-differential photoionization rate $w_n^{\rm Eik}(\theta)$ for individual n-th ATI channel in regime of intensive laser field (θ is an angle between $\mathbf{p}$ and $\mathbf{F}$). Technically the calculations are very simple requiring a single numerical integration. The results are compared with the rates $w_n^{\rm PP}(\theta)$ obtained by using Eq. (1), where $w_{\rm sr}$ was evaluated within the recent amendment of the Keldysh scheme that made it quantitatively reliable for a short-range interaction [4].

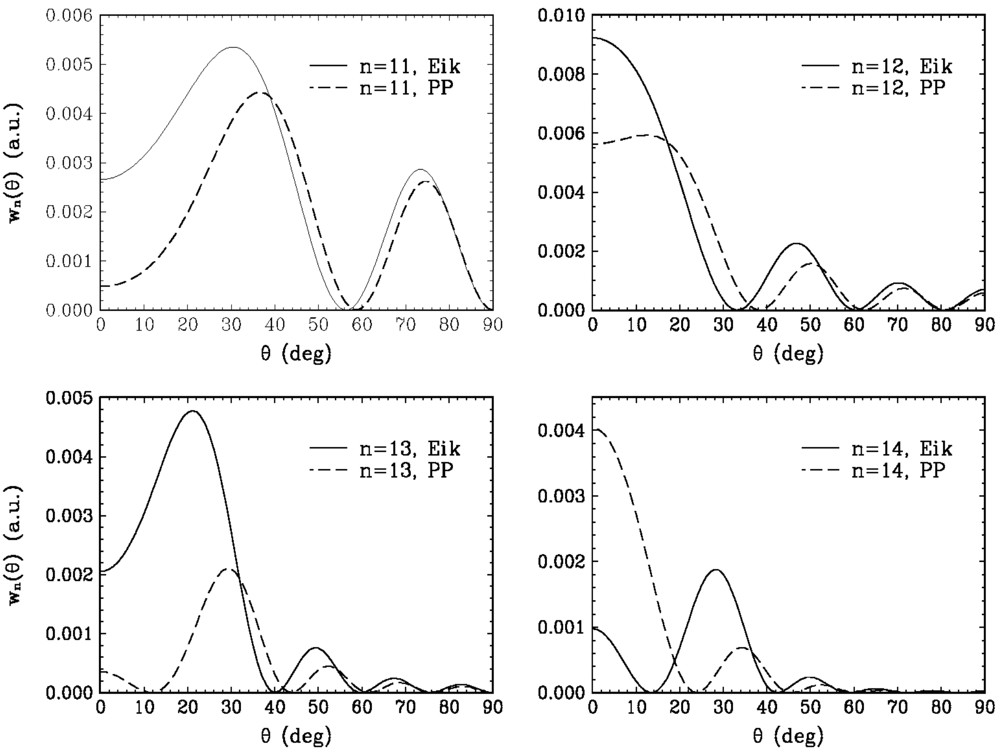

Figure 1: Angle-differential photoionization rates $w_n(\theta)$ for four lowest open ATI channels labeled by a number of absorbed photons n ($n = 11$ corresponds to the lowest open ATI channel). Hydrogen atom is illuminated by the laser wave with frequency $\omega = 2$ eV and intensity $I = 10^{14}$ W/cm^2; solid curves – present eikonal theory, dashed curves – $w_n^{\rm PP}(\theta)$.

For the angle-integrated partial rates the difference between $w_n^{\rm Eik}$ and $w_n^{\rm PP}$ is relatively small. However the angular distributions substantially differ. The overall shapes are similar for two lowest open ATI channels, see Fig. 1. For higher channels a drastic difference is found.

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