Publ. Astron. Obs. Belgrade No. 89 (2010), 45-48 *Contributed Paper*

IONIZATION TRANSITION RATE FOR CIRCULARLY POLARIZED FIELDS, FOR DIFFERENT Z, INCLUDING NON-ZERO INITIAL MOMENTUM

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Abstract. As we have recently shown that the momentum of the ejected electron influences the transition rate in the case of ADK-theory, so we are now examining how the change of atom charge Z, non-zero momentum included, contributes to transition rates.

1. INTRODUCTION

There is a widespread opinion that the principle goal of the research is to go after the latest development in technology, if not in front of it. Meaning, in the case of tunnel ionization, that the frontal research is working with laser field intensities of 10^{21}W/cm^2, and higher. But there are researchers who won't go over the limit of 10^9 W/cm^2, (Gamaly et al. 2008) because it destroys the atom irepairably... Here we do not advocate either of the approaches, offering only going into the depth of the problem.

It was shown, Ristic et al. (2008) how the non-zero momentum of the ejected electron changes the transition rate in the case of ADK-theory (Ammosov et al. 1986, Krainov et al. 1992) so we are now examining how the change of atom charge Z, non-zero momentum included, contributes to transition rates.

Transition rate formula for circularly polarized field (in cases of zero momentum) was obtained earlier (atomic unit system $\hbar = m_e = e = 1$, is used here and throughout the paper) Ristic et al. (2009)

$$W_{\mathrm{ADK}}^{\mathrm{cir}} = \left(\frac{3FZ^3}{\pi n^{*3}}\right)^{1/2} \left(\frac{4Z^3 e}{Fn^{*4}}\right)^{2n^*-1} \exp\left(-\frac{2Z^3}{3Fn^{*3}}\right) \tag{1}$$

But we shall use a bit modified expression, including the non-zero initial momentum into the expression (1), Ristic et al. (2009]

$$W_{pADK}^{cir} = \left(\frac{3FZ^3}{\pi n^{*3}}\right)\left(\frac{4Z^3 e}{Fn^{*4}}\right)^{2n^*-1} \exp\left(-\frac{2Z^3}{3Fn^{*3}} - \frac{p^2\gamma^3}{3\omega}\right) \tag{2}$$

Expression for momentum, obtained in Bauer (1997) also will be used

$$p(\eta) = \sqrt{-\frac{1}{4} + \frac{1}{2\eta} + \frac{1}{4\eta^2} + \frac{F}{4}\eta} \tag{3}$$

2. CALCULATING THE TRANSITION RATES FOR CIRCULARLY POLARIZED LASER FIELDS INCLUDING NONZERO MOMENTUM, FOR DIFFERENT CHARGE Z

Thus we calculated transition rates for ejected electrons for various atomic charge Z. The procedure is experimentally founded in Yamakawa et al. (2004). Our results are shown on 3D and 2D graphs in Figs. 1-4. As parameters γ and n* include in themselves ionization potential E_i: $\gamma = \frac{\omega}{F} \cdot \sqrt{2 \cdot E_i}$; $n^* = \frac{Z}{\sqrt{2 \cdot E_i}}$, we, as is done in experiments (Yamakawa et al. 2004) and also analyzed in Ristic et al (2007) define and calculate the change of ionization energy for each ejected electron. So graphs shown are depending on various η[1,300], and on field intensities I=10^{13}, 10^{14}, 10^{15}, 10^{16}, 10^{17} W/cm^2 (fixed for each separate graph).

In order to mark the difference between the case of zero momentum of the ejected electron and non-zero momentum we have shown the transition rates maxima, depending on intensity of lasers and parabolic coordinate η.

In the upper left corner of Figures there is always value of ion charge number Z, and the corresponding ionization energy (atomic unit system).

Z=2, E_2=1.16

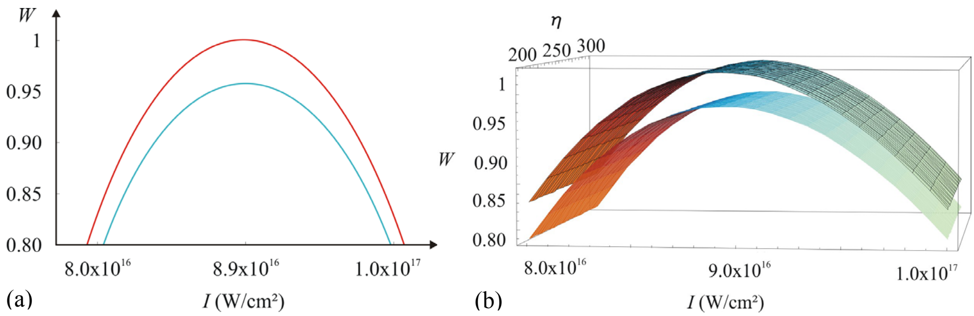

Figure 1.a, b: Transition rates W^{cir}_{ADK} and W^{cir}_{pADK} dependence on field intensity, for zero initial momentum and non-zero initial momentum, respectively (enlarged parts), Z = 2; **a)** for η fixed at 190 (2D graph); **b)** η varying (3D graph).

One should notice considerably large gap between the curves, indicating that the transition rate for ejected electrons with zero initial momentum and the transition rate for electrons with non-zero momentum are different (the second are much lesser).

$Z=3$, $E_3=1.68$

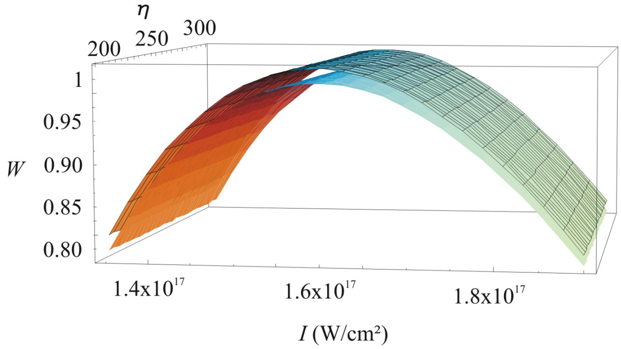

Figure 2: Transition rates $W^{cir}{}_{ADK}$ and $W^{cir}{}_{pADK}$ dependence on field intensity, for zero initial momentum and non-zero initial momentum, respectively, Z = 3.

The gap between curves is reduced, showing that the transition rate for ejected electrons with zero initial momentum and the transition rate for electrons with non-zero momentum are getting lesser.

$Z=4$, $E_4=2.24$

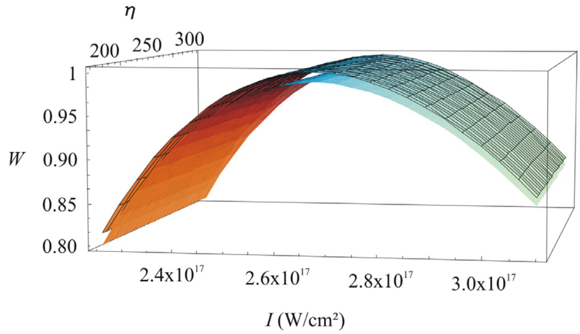

Figure 3: Transition rates $W^{cir}{}_{ADK}$ and $W^{cir}{}_{pADK}$ dependence on field intensity, for zero initial momentum and non-zero initial momentum, respectively, Z = 4.

Here the gap-effect is continuing to show itself, being smaller and smaller. See also the forthcoming Figures.

Comparing Figs. 1-4 one can notice the lesser difference between two curves, the greater Z. It could be explained by the greater ionization energy needed for multiple ionized atoms.

Z=5, E_5=3.04

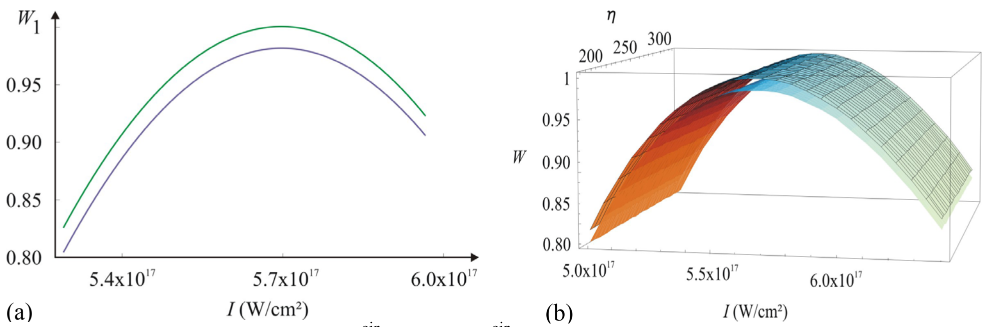

Figure 4 a, b: Transition rates $W^{cir}{}_{ADK}$ and $W^{cir}{}_{pADK}$ dependence on field intensity, for zero initial momentum and non-zero initial momentum, respectively, Z = 5; **a)** for η fixed at 190 (2D graph); **b)** η varying (3D graph).

Namely, as Z is increasing the influence of ejected electrons momenta on transition rates is decreasing, because much more photons from laser beam are used for overcoming the binding energy in the ion for greater Z. Therefore there is much less photons which could increase the momentum of ejected electrons.

3. FINAL REMARKS

We have noticed that as Z increases, the influence of non-zero momentum of ejected electrons decreases. It is due to the fact that more and more photons from the laser beam are used to overcome the binding energy in the multiply ionized atom, and there are lesser photons for increasing the initial momentum of ejected electrons.

Also, though maxima are at the same laser intensities, in the case of zero momentum the transition rate is greater (especially 2D graphs).

Acknowledgement

This work was supported in part by the Ministry of Science, Republic of Serbia (Project 141023).

References

Ammosov, V. M., Delone, N. B., Krainov, V. P.: 1986, *Sov. Phys. JETP*, **64,** 1191.
Bauer, D.: 1997, *Phys. Rev. A* **55** , 55.
Gamaly, E. G., Juodkazis, S., Mizeikis, V., Misawa, H., Rode, A. V., Krolikowski, W. Z., Kitamura, K.: 2008, *Current Applied Physics*, **8**, 416.
Krainov, V. P., Ristić, V. M: 1992, *Sov. Phys. JETP*, **101**, 1479.
Ristić, V. M., Miladinović, T. B., Radulović, M. M.: 2008, *Laser Phys*., **18**, 10.
Ristić, V. M., Miladinović, T. B., Radulović, M.M.: 2009, *Acta Phys. Pol. A* ,**116**, 504.
Ristić, V. M., Stevanović, J. M.: 2007, *Laser Phys Lett*., **4**, 354.
Yamakawa, K., Akahane, Y., Ukuda, Y., Aoyama, M., Inoue, N., Ueda, H., Utsumi T.: 2004, *Phys, Rev Lett*., **92**, 123001.