Tunneling Ionization Study of Linear Molecules in Strong-Field Laser Pulses

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Abstract. We theoretically studied photoionization of atoms and molecules in the frame of Perelomov-Popov-Terent'ev (PPT) and Ammosov-Delone-Krainov (ADK) theories. Strong-field single ionization of two diatomic molecules, N_2 and O_2, are studied and compared to Ar and Xe atoms, using an 800 nm Ti:sapphire laser in the 10^{13} to 10^{15} Wcm^{-1} intensity range. To eliminate disagreement between theoretical and experimental findings in a low intensity fields, we considered the influence of shifted ionization potential. Including these effects in the ionization rates, we numerically solved rate equations in order to determine an expression for the ionization yields. The use of modified ionization potential showed that the ionization yields will actually decrease below values predicted by original (uncorrected) formulas. This paper will discuss the causes of this discrepancy.

1. Theoretical Background

Standard ionization rates

$$W_{MOADK} = \frac{B^2(m)}{2^{|m|}|m|!}\frac{1}{\kappa^{\frac{2Z_C}{\kappa}-1}}\left(\frac{2\kappa^3}{F}\right)^{2Z_C/\kappa-|m|-1}\text{Exp}\left[-\frac{2\kappa^3}{3F}\right]$$

$$W_{MOPPT} = \frac{B^2(m)}{2^{|m|}|m|!}\frac{A_m(\omega,\gamma)}{\kappa^{2Z_C/\kappa-1}}\left(\frac{2\kappa^3}{F((1+\gamma^2)}\right)^{2Z_C/\kappa-|m|-1}\times\text{Exp}\left[-\left(\frac{2\kappa^3}{3F}\right)g(\gamma)\right]$$

$$I_p \to I_p^{corr}$$

$$I_p^{corr} = I_p + I_{st} + U_p = I_p + \frac{\alpha_p F^2}{4} + \frac{\gamma_h F^4}{24} + \frac{F^2}{4\omega^2}$$

Corrected ionization rates

$$W_{MOADK}^{corr}(t) = \frac{B^2(m)}{2^{|m|}|m|!}\frac{1}{\sqrt{2I_p^{corr}(t)}^{\,2Z_C/\sqrt{2I_p^{corr}(t)}-1}}\left(\frac{2(2I_p^{corr}(t))^{3/2}}{F_G(t)}\right)^{2Z_C/\sqrt{2I_p^{corr}(t)}-|m|-1}$$

$$\times\,\text{Exp}\left[-\frac{2(2I_p^{corr}(t))^{3/2}}{3F_G(t)}\right]$$

$$W_{MOPPT}^{corr}(t) = \frac{B^2(m)}{2^{|m|}|m|!}\frac{A_m^{corr}(\omega,\gamma^c(t))}{\sqrt{2I_p^{corr}(t)}^{\,2Z_C/\sqrt{2I_p^{corr}(t)}-1}}\times$$

$$\times\left(\frac{2(2I_p^{corr}(t))^{3/2}}{F_G(t)(1+(\gamma^c(t))^2)}\right)^{2Z_C/\sqrt{2I_p^{corr}(t)}-|m|-1}\text{Exp}\left[-\left(\frac{2(2I_p^{corr}(t))^{3/2}}{3F_G(t)}\right)g(\gamma^c(t))\right]$$

2. Results

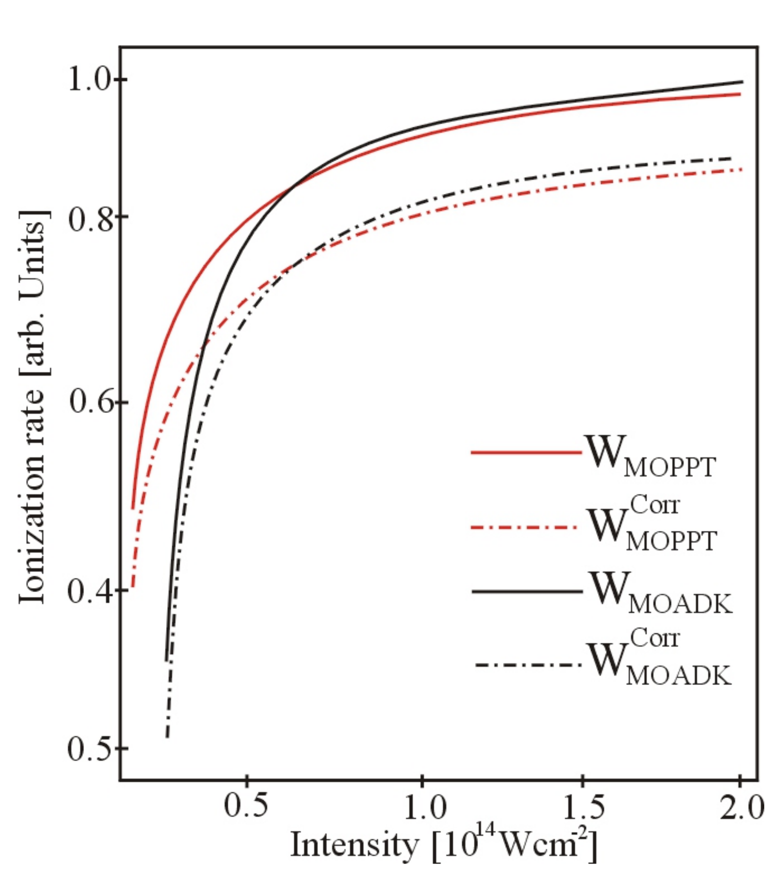

Fig. 1. Comparative review of the ionization rates for O_2molecule as a function of the laser intensity. The following notation is used: solid line for uncorrected ionization potential, I_p, and dot-dashed for fully corrected ionization potential, I_p^{corr}. Red lines are from the corrected MO-PPT and black from the MO-ADK model.

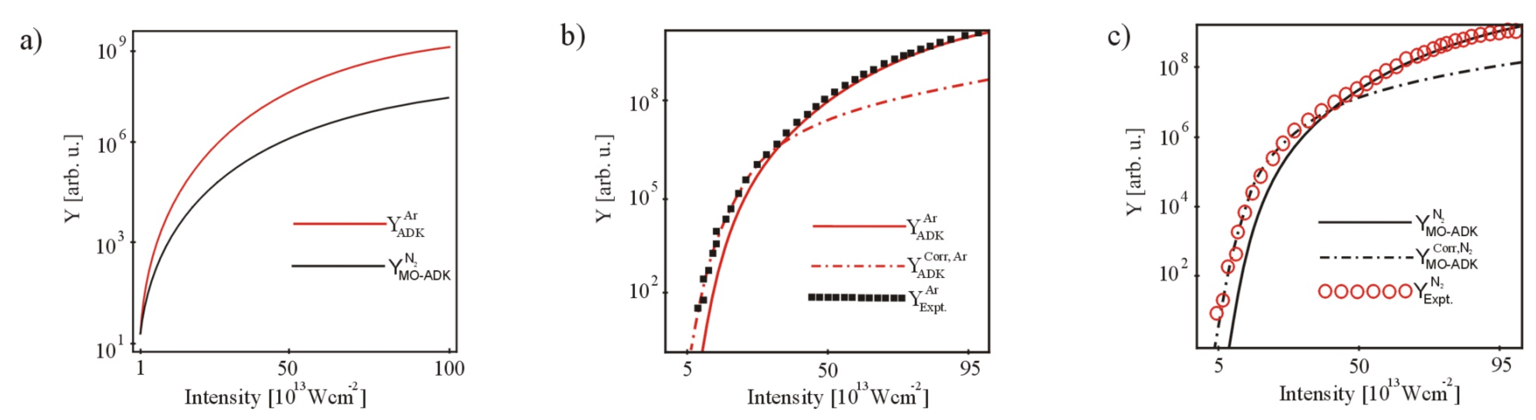

Fig. 2. Yield as a function of laser field intensity. In all panels, the pulse duration is 30 fs and the laser wavelength is at 800 nm. We used the ADK and MO-ADK theory. The experimental data are from [C. Guo, M. Li, J.P. Nibarger, and G.N. Gibson, Physical Review A 58(6) (1998) p.R4271]. For all graphs the following notation is used: red line for Ar atom, black line for N_2 molecule. Experimental results are shown as black squares for Ar atom and as red open circles for N_2 molecule.

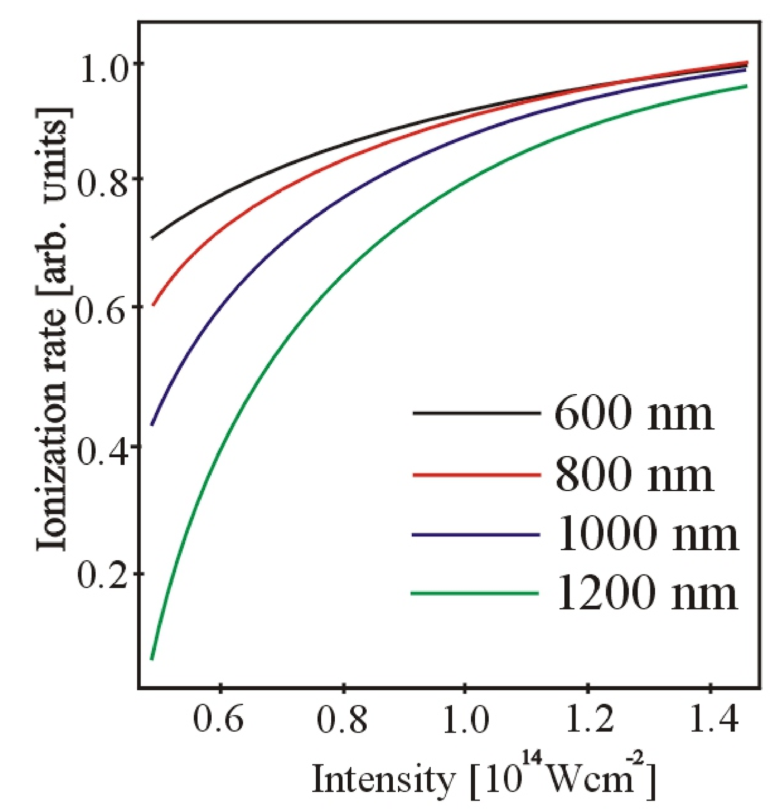

Fig. 3. Comparison of the ionization rates predicted by the MO-PPT model of molecule N_2 as a function of laser filed intensity at four different central wavelengths, λ, of: (black line) 600 nm, (red line) 800 nm, (blue line) 1000 nm and (green line) 1200 nm. The laser field is taken to be a Gaussian pulse with a pulse duration (full width at half maximum) of τ = 20 fs.

3. Conclusion

In conclusion, we have analyzed the influence of the ionization potential correction on the tunneling ionization rate for diatomic molecular system. Comparisons are made among the different versions of strong-field approximation. Our results clearly indicated that the correction of ionization potential effects the rate, by decreasing it. Also, some results show that the beam shape significantly influences the observed quantities.

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