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2012 J. Phys.: Conf. Ser. 388 032004

(http://iopscience.iop.org/1742-6596/388/3/032004)

Journal of Physics: Conference Series **388** (2012) 032004 doi:10.1088/1742-6596/388/3/032004

# Closure approximation in the theory of two-photon double ionization of atoms

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**Synopsis** We consider two-photon double ionization of helium with 100, 200, and 400 eV excess energy. We focus on the case of ultrashort pulses and develop an approach to calculate the two-photon transition matrix elements within the lowest order of the time-dependent perturbation theory. It is shown, that in the subfemtosecond regime the intermediate Green's function can be successfully evaluated by means of the closure approximation.

The two-photon transition matrix element calculated by means of the second order of the time-dependent perturbation theory in the length gauge, may be written as follows

$$A_{fi}^{(2)} = \mathcal{E}_0^2 \left(\frac{1}{i}\right)^2 \int_{-\infty}^{\infty} d\tau_2 \int_{-\infty}^{\tau_2} d\tau_1 \; F(\tau_2) e^{iE_f\tau_2} F(\tau_1) e^{-iE_i\tau_1} < f|D_L e^{-i(\tau_2-\tau_1)H} D_L|i >, \quad (1)$$

where $H$ is the full Hamiltonian, $\mathcal{E}_0$ the field amplitude, $D_L = \mathbf{e}\cdot(\mathbf{r}_1+\mathbf{r}_2)$, $F(\tau)$ a pulse time-profile, and $\mathbf{e}$ the field polarization vector. It is possible to find arguments [1] that within the resonance condition (energy conservation) $E_f - E_i \approx 2\omega_0$ the Green's function in (1) can be replaced by the unit operator in the case of high energy photons and ultrashort pulses (two oscillations of the field), i.e.

$$A_{fi}^{(2)} \approx K(\mathcal{E}_0, \omega_0, E_i, E_f) < f|D_L^2|i > . \quad (2)$$

Eq. (2) includes three terms, the first one is related to one-photon absorption by each electron (dipole transition), and two others refer to two-photon absorption by one of electrons (quadrupole terms).

The calculations on the basis of eq. (2) were carried out for different tightly and loosely correlated initial and final wave functions. For example, in Fig.1 the differential probability $d^4W/EdEdxd\Omega_1 d\Omega_2$ is presented versus the energy sharing variable $x = E_1/(E_1+E_2)$ for back-to-back electron emission. The initial [2] and final [3] stationary states are presented by highly correlated functions.

All results collected in [1] unveil the crucial role of electron correlations in this transient regime of ionization which is neither sequential nor direct now. We have found that even in the high frequency regime, the two processes are important in contrast to a pure sequential double ejection mechanism where each electron absorbs, independently, a single photon.

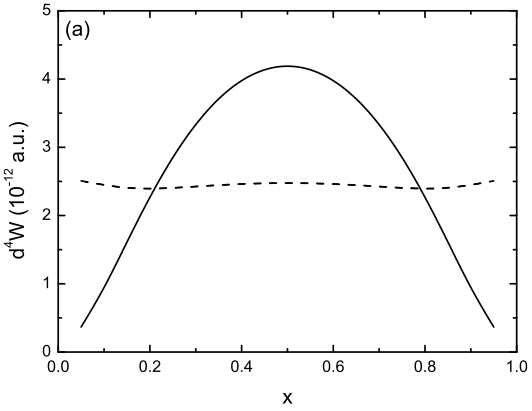


**Figure 1**. Differential probability in a.u. versus $x$ (see text). $E = E_1+E_2 = 100$ eV. Solid line: results obtained by including both dipole and quadrupole transitions in (2); dashed line: results obtained by neglecting the quadrupole terms. $|K|$=0.000132.

## References

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