ФІЗИЧНІ, ХІМІЧНІ ТА ІНШІ ЯВИЩА, НА ОСНОВІ ЯКИХ МОЖУТЬ БУТИ СТВОРЕНІ СЕНСОРИ

PHYSICAL, CHEMICAL AND OTHER PHENOMENA, AS THE BASES OF SENSORS

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SPECTROSCOPY OF ATOMS IN A STRONG LASER FIELD: NEW METHOD TO SENSING AC STARK EFFECT, MULTIPHOTON RESONANCES PARAMETERS AND IONIZATION CROSS-SECTIONS

V. V. Buyadzhi, A. V. Glushkov, V. F. Mansarliysky, A. V. Ignatenko, A. A. Svinarenko

Odessa State Environmental University, L'vovskaya str.15, Odessa-16, 65016, Ukraine
E-mail: buyadzhivv@gmail.com

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Abstract. The new consistent approach to atom in a strong realistic laser field, based on the relativistic energy formalism (S-matrix adiabatic formalism), relativistic Dirac equation Green function method and relativistic many-body perturbation theory with the Dirac-Kohn-Sham zeroth approximation, is applied to studying the resonant multiphoton resonances shifts and widths and ionization cross-sections. An approach to treating the multiphoton atomic processes is outlined on example of H, Cs, Kr,Mg etc. Analysis shows that the shift and width of the multi-photon resonance line for the interaction "atom- multimode laser pulse" is greater than the corresponding shift and width for a case of the "atom- single-mode pulse" (the Lorenz pulse model) interaction. From the physical point of view it is naturally provided by action of the photon-correlation effects and influence of the laser pulse multi-modity.

Keywords: laser field, sensing multiphoton resonances, energy approach, Green function method

СПЕКТРОСКОПІЯ АТОМІВ В СИЛЬНОМУ ЛАЗЕРНОМУ ПОЛІ: НОВИЙ МЕТОД ВИЗНАЧЕННЯ ПАРАМЕТРІВ АС ЕФЕКТУ ШТАРКА, БАГАТОФОТОННИХ РЕЗОНАНСІВ ТА ПЕРЕРІЗІВ ІОНІЗАЦІЇ

В. В. Буяджи, О. В. Глушков, В. Ф. Мансарлійський, Г. В. Ігнатенко, А. А. Свинаренко

Анотація. Новий послідовний підхід в спектроскопії атому в сильному реалістичному лазерному полі, оснований на релятивістському енергетичному формалізмі (S-матричний адіабатичний формалізм), методі релятивістської функції Гріна рівняння Дірака і релятивістській теорії збурень с Dirac-Kohn-Sham нульовим наближенням , застосовується для вивчення енергій та ширин багатофотонних резонансів, перерізів іонізації. Підхід застосовано до кількісного розгляду багатофотонних процесів в атомах H, Cs, Kr,Mg та інших. Аналіз показує, що зсув і ширина лінії багатофотонного резонансу при взаємодії атома з багатомодовим лазерним імпульсом (гаусова форма імпульсу) більше, ніж відповідний зсув і ширина у випадку взаємодії атома з лазерним імпульсом лоренцевої форми. З фізичної точки зору це, природно, забезпечується дією фотон-кореляційних ефектів і впливом модовой структури імпульсу лазерного випромінювання.

Ключові слова: лазерне поле, багатофотонні резонанси, енергетичний формалізм, метод функції Гріна

СПЕКТРОСКОПИЯ АТОМОВ В СИЛЬНОМ ЛАЗЕРНОМ ПОЛЕ: НОВЫЙ МЕТОД ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ АС ЭФФЕКТА ШТАРКА, МНОГОФОТОННЫХ РЕЗОНАНСОВ И СЕЧЕНИЙ ИОНИЗАЦИИ

В. В. Буяджи, А. В. Глушков, В. Ф. Мансарлийский, А. В. Игнатенко, А. А. Свинаренко

Аннотация. Новый последовательный подход в спектроскопии атома в сильном реалистичном лазерном поле, основанный на релятивистском энергетическом формализме (S-матричный адиабатический формализм), методе релятивистской функции Грина уравнения Дирака и релятивистской теории возмущений с Dirac-Kohn-Sham нулевым приближением, применяется для изучения энергий и ширин многофотонных резонансов, сечений ионизации. Подход применен к количественному изучению многофотонных процессов в атомах H, Cs, Kr, Mg и др. Анализ показывает, что сдвиг и ширина линии многофотонного резонанса при взаимодействии атома с многомодовым лазерным импульсом (гауссова форма импульса) больше, чем соответствующий сдвиг и ширина в случае взаимодействия атома с лазерным импульсом лоренцевой формы. С физической точки зрения это, естественно, обеспечивается действием фотон-корреляционных эффектов и влиянием модовой структуры импульса лазерного изления.

Ключевые слова: лазерное поле, многофотонные резонансы, энергетический формализм, метод функций Грина

1. Introduction

At the present time a physics of multiphoton phenomena in atoms, molecules ets has a great progress that is stimulated by development of new laser technologies (see Refs. [1-10]). The appearance of the powerful laser sources allowing to obtain the radiation field amplitude of the order of atomic field in the wide range of wavelengths results to systematic investigations of the nonlinear interaction of radiation with atomic and molecular systems [1-17]. The interaction of atoms with the external alternating fields, in particular, laser fields, has been the subject of intensive experimental and theoretical studies. A definition of the k-photon emission and absorption probabilities and atomic levels shifts, study of dynamical stabilization and field ionization etc are the most actual problems to be solved. At present time, a progress is achieved in the description of the processes of interaction atoms with the harmonic emission field [1]. But in the realistic laser field the according processes are in significant degree differ from ones in the harmonic field. It has been proved a significant role of the photon-correlation effects and influence of the laser pulse multimodity. Surely, a number of different theoretical approached has been developed in order to give a adequate description of the atoms in a strong laser field. Here one could mention such approaches as the standard perturbation theory (surely for low laser filed intensities), non-relativistic Green function method, the density-matrix formalism, time-dependent density functional formalism, direct numerical solution of the Schrödinger (Dirac) equation, multi-body multi-photon approach, the time-independent Floquet formalism etc (see [2-15] and Refs. therein).

Earlier the relativistic energy approach to studying the interaction of atom with a realistic strong laser field, based on the Gell-Mann and Low S-matrix formalism, has been developed. Originally, Ivanov etal has proposed an idea to describe quantitatively a behaviour of an atom in a realistic laser field by means studying the radiation emission and absorption lines and further the theory of interaction of an atom with the Lorenz laser pulse and calculating the corresponding lines moments has been in details developed in Ref. [4-6]. Theory of interaction of an atom with the Gauss and soliton-like laser pulses and calculating the corresponding lines moments has been presented in [7,8].

Here we present a new consistent approach to atom in a strong realistic laser field, based on the relativistic energy formalism and relativistic Dirac equation Green function method [9-12] and apply it to studying the resonant multiphoton resonances shifts and widths and ionization cross-sections for concrete systems.

2. Relativistic energy approach and Green function method to atom in a strong laser field

The relativistic energy approach in the different realizations and the radiation lines moments technique is in details presented in Refs. [8,9]. So, here we are limited only by presenting the master elements. In the theory of the non-relativistic atom a convenient field procedure is known for calculating the energy shifts δE of degenerate states. This procedure is connected with the secular matrix M diagonalization. In constructing M, the Gell-Mann and Low adiabatic formula for δE is used [5]. In relativistic theory, the Gell-Mann and Low formula δE is connected with electrodynamical scattering matrice, which includes interaction with as a laser field as a photon vacuum field. A case of interaction with photon vacuum is corresponding to standard theory of radiative decay of excited atomic states. Surely, in relativistic theory the secular matrix elements are already complex in the second perturbation theory (PT) order. Their imaginary parts are connected with radiation decay possibility. The total energy shift is usually presented in the form:

$$\delta E = \mathrm{Re}\delta E + i\,\mathrm{Im}\delta E\,,\ \ \mathrm{Im}\,\delta E = -P/2 \qquad (1)$$

where P is the level width (decay possibility). Spectroscopy of an atom in a laser field is fully defined by position and shape of the radiation emission and absorption lines. The lines moments μ_n are strongly dependent upon the laser pulse quality: intensity and mode constitution [4-6]. Let us describe the interaction “atom-laser field” by the potential [5]:

$$V(r,t) \sim V(r)\int d\omega f(\omega-\omega_0)\cos\,[\omega_0(t+\tau)], \qquad (2)$$

Here ω_0 is the central laser radiation frequency. The potential V represents the infinite duration of laser pulses with known frequency τ. The function $f(\omega)$ is a Fourier component of the laser pulse. The condition $\int d\omega f^2(\omega)=1$ normalizes potential $V(rt)$ on the definite energy in the pulse. Let us consider the pulses with Lorentz shape (coherent 1-mode pulse): $f(\omega) = \beta\exp(\omega^2+\Delta^2)$, Gaussian one (multi-mode chaotic pulse): $f(\omega) = \beta\exp[\ln 2(\omega^2/\Delta^2)]$ (β -normalizing multiplier). A case of the Lorentz shape has been earlier studied [4-6]. A case of the Gauss and soliton-like shape is considered in Refs.[7-9]. The master program results in the calculating an imaginary part of energy shift $\mathrm{Im}\delta E_\alpha(\omega_0)$ for any atomic level as the function of the central laser frequency ω_0. An according function has the shape of the resonance, which is connected with the transition f-i (f, i-discrete levels) with absorption (or emission) of the "k" number of photons. For the resonance we calculate the following values [5]:

$$\delta\omega(\text{f-i}|k)=\int' d\omega\ \mathrm{Im}\ \delta E_\alpha(\omega)(\omega - \omega_{fi}/ k)/N,$$
$$\mu_m = \int' d\omega\ \mathrm{Im}\ \delta E_\alpha(\omega)\ (\varpi - \omega_{fi} / k)^m / N, \quad (3)$$

where $\int' d\omega \mathrm{Im} E_i$ is the normalizing multiplier; $\omega_{p\alpha}$ is position of the non-shifted line for transition f-i, $\delta\omega(\mathrm{fi}|k)$ is the line shift under k-photon absorption; $\varpi_{fi}=\omega_{fi}+ k\cdot\delta\omega(\mathrm{fi}|k)$. The first moments μ_1, μ_2 and μ_3 determine the atomic line centre shift, its dispersion and the asymmetry. To find μ_m, we need to get an expansion of E_i to PT series: $E_i = \Sigma E_i^{(2k)}(\omega_0)$. One may use here the Gell-Mann and Low adiabatic formula for δE_i :

$$\delta E_i=\lim_{\gamma\to 0} i\gamma g \ln\langle\Phi_i|S_\gamma(0,-\infty|g)|\Phi_i\rangle|_{g=1} \quad (4)$$

The representation of the S- matrix in the form of the PT series induces the expansion for δE_i:

$$\delta E_i(\omega_0) = i \lim_{\gamma\to 0} \gamma \sum_{k_1 k_2 \ldots k_n} \lambda(k_1, k_2,\ldots,k_n) \prod_{j=1} S_\gamma^{(kj)}, \quad (5)$$

$$S_\gamma^{(m)} = (-1)^m \int_{-\infty}^{0} d\,t_1 \ldots \int_{-\infty}^{t_m -1} d\,t_m \times \quad (6)$$
$$\times \langle\Psi_i| \prod_{n=1}^{m} e^{(iH^{DKS}t_n)} V(rt_n) e^{(-iH^{DKS}t_n)} e^{\gamma t_n} |\Psi_i\rangle,$$

Here H is the atomic hamiltonian, $\lambda(k_1, k_2,\ldots,k_n)$ are the numerical coefficients. The structure of matrix elements $S_\gamma^{(m)}$ is in details described in [5,6,8]. Here we only note that one may to simplify a consideration by account of the k-photon absorption contribution in the first two PT orders. Besides, summation on laser pulse is exchanged by integration. The corresponding (l+2k+1)-times integral on (l+2k) temporal variables and r ($l=0,2$) (integral I_γ) are calculated [5,6]. Finally, after some cumbersome transformations one can get the expressions for the line moments. The corresponding expressions for the Gaussian laser pulse are as follows:

$$\delta\omega(if|k)=[\sigma/k(k+1)]\sum_l\{<i|V|l><l|V|i>/(\omega_{il}+\omega_{if}/k)+$$
$$+<i|V|l><l|V|i>/(\omega_{il}-\omega_{if}/k)- \quad (7)$$
$$-<f|V|l><l|V|f>/(\omega_{fl}+\omega_{if}/k)-<f|V|l><l|V|f>/(\omega_{fl}-\omega_{if}/k)\}$$
$$\mu_2 = \sigma\Delta^2/k,$$
$$\mu_3 = \{4\pi\Delta^3/[\mathrm{k}(\mathrm{k}+1)]\}\sum\{<i|V|l><l|V|i>/(\omega_{il}+\omega_{if}/k)+$$
$$+<i|V|l><l|V|i>/(\omega_{il}-\omega_{if}/k)-$$
$$-<f|V|l><l|V|f>/(\omega_{fl}+\omega_{if}/k)-<f|V|l><l|V|f>/(\omega_{fl}-\omega_{if}/k)\}$$

The summation in (7) is over all atomic states. Let us note that these formulas for the Gaussian pulse differ of the Lorenz shape laser pulse expressions [5,6]. The parameters (7) are naturally linked with the AC Stark effect parameters. The key characteristics of the multiphoton process is a multiphoton ionization cross-section. According to standard definition for one-quasiparticle atom say two-photon cross-section is naturally linked with the square of the two-order amplitude $|M_{fi}|$ (see, for example [3,5,11]) as:

$$\sigma_2 = \frac{8\pi^3}{\alpha^2 E_\gamma^2} \sum_{\kappa_f m_f} \frac{1}{2j_i+1} \sum_{m_i} |M_{fi}^{(2)}(\lambda)|^2 \quad (8)$$

$$M_{fi}^{(2)}(\lambda)=\left\langle \psi_{E_f\kappa_f m_f} |\alpha u_\lambda e^{-ikr}| G_{E_{n_i\kappa_i}+E_\gamma} |\alpha u_\lambda e^{-ikr'}| \psi_{n_i\kappa_i m_i} \right\rangle \quad (9)$$

where u_λ is a polarization vector, k –is a wave vector, G_E –id the Green function. The key block of the method is definition of the relativistic Green function for the Dirac equation. In ref. [12] it has been presented an advanced approach to construction of the electron Green's function of the Dirac equation with a non-singular central nuclear potential and complex energy. The Fermi-model and relativistic mean-field potentials are used. The radial Green's function is represented as a combination of two fundamental solutions of the Dirac equation. The approach proposed includes a procedure of generating the relativistic electron functions of the Dirac-Kohn-Sham basic method [11] with performance of the gauge invariance principle. In order to reach the gauge invariance principle performance we use earlier developed QED perturbation theory treating. In the fourth order of the QED perturbation theory (PT) there are diagrams, whose contribution into imaginary part of radiation width Im δE for the multi-electron system accounts for multi-body correlation effects [5]. A minimization of the functional ImδE leads to integral-differential Dirac-Kohn-Sham-like density functional equations [5,11]. Further check for the gauge principle performance is realized by means of the Ward identities.

In the numerical procedure we use the effective Ivanova-Ivanov's algorithm, within which a determination of the Dirac equation fundamental solutions is reduced to solving the single system of the differential equations. Finally the computational procedure results in a solution of the ordinary differential equations system for above described functions and integrals. In concrete numerical calculations the PC "Superatom-ISAN" package is used. The construction of the operator wave functions basises within the relativistic PT with the Dirac-Kohn-Sham-zeroth approximation [12], the technique of calculating the matrix elements and other details is are presented in Refs. [4-12].

3. Results and conclusions

Below we present the results of calculating the multi-photon resonances and ionization parameters for a few atoms in a laser field and analyse photon-correlation effects. We start from results of the numerical calculation for the three-photon resonant, four-photon ionization profile of atomic hydrogen (1s-2p transition; wavelength =365 nm). In figure 1 we present the shift s (=δω) and width (w) of the resonance profile as the function of the mean laser intensity at the temporal and spatial center of the UV pulse.

Further let us consider the spectroscopic results for three-photon transition 6S-6F in the Cs atom (wavelength 1,059 μm; see figure 2). The detailed experimental study of the multi-photon processes in Cs atom has been carried out by Lompre et al [15]. Lompre et al experimentally studied a statistics of the laser radiation and there are measured the characteristics of the multi-photon ionization. The line shift is linear to respect to the laser intensity (laser intensity is increased from 1.4 to 5.7×10^{7} W/ cm^{2}) and is equal (a case of the gaussian multi-mode laser pulse): $\delta\omega(fi|k) = bI$ *with* $b=(5{,}6\pm0{,}3)\ cm^{-1}/GW\times cm^{-2}$ (*b* is expressed in terms of energy of the three-photon transition 6S-6F). The corresponding shift obtained with coherent (one-mode) laser pulse is defined as follows: $\delta\omega_{0}(fi|k)=aI$, $a=2cm^{-1}/GW\cdot cm^{-2}$. Theoretical values, obtained with using no-optimized atomic basis's, are as follows: i). for the gaussian multi-mode pulse (chaotic light): $\delta\omega(fi\mid k) = bI$ *withb*$=5{,}8\ cm^{-1}/GW\cdot cm^{-2}$; iii). for the coherent one-mode pulse: $\delta\omega_{0}(fi\,|k)=aI$, $a=2{,}1\ cm^{-1}/GW\cdot cm^{-2}$ [8].

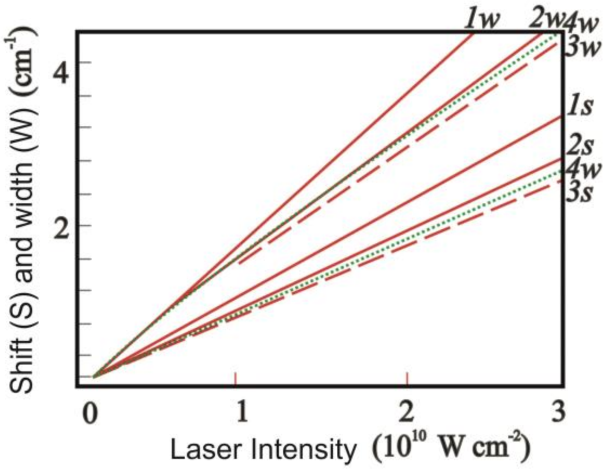


Figure 1. Shift (S) and width (W) of resonant profile as laser intensity function: experiment – 3s , 3w (Kelleger et al); theory of Zoller- 1s,1w; Glushkov etal, 2s,2w; 4s,4w – our data

Our theoretical values are as follows: i). the gaussian multi-mode pulse (chaotic light) $\delta\omega(fi|k) = bI$, $b=5{,}62\ cm^{-1}/GW\times cm^{-2}$; ii). the coherent one-mode pulse: $\delta\omega_{0}(fi\,|k)=aI$, $a=2{,}01\ cm^{-1}/GW\cdot cm^{-2}$; For the with multi-mode pulse, the radiation line shift is significantly larger (in ~ 3 times), then the corresponding shift, which is for 1-mode pulse. In fact the radiation line shift is enhanced by the photon-correlation effects. In figure 2 we present the results of calculation for the multi-photon resonance width for transition 6S-6F in Cs (wavelength 1059 nm) in dependence upon the laser intensity and compare them with experimental data and alternative theoretical data.

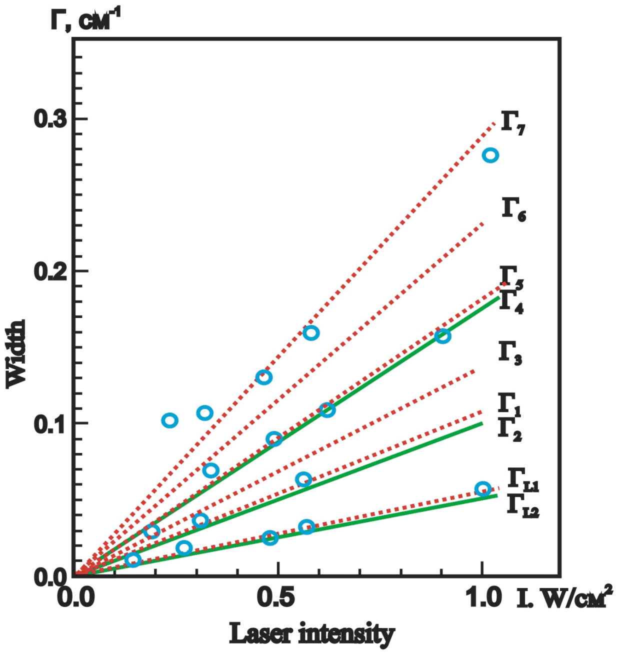


Figure 2. The multi-photon resonance width for transition 6S-6F in the atom of Cs (wavelength 1059nm) in dependence upon the laser intensity I (10^8 W/cm^2): experiment - o (Grance, 1981; Lompre et al, 1981); Theory: this work, dotted lines - Γ_{L1}, Γ_1, Γ_3, Γ_5, Γ_6, Γ_7 - widths for single-mode Lorentz laser pulse and multi-mode Gauss laser pulse respectively with line band 0.03, 0.055, 0.08, 0115 and 0.15cm^{-1} respectively; data by Glushkov et al, continuous lines - Γ_{L2}, Γ_2, Γ_4 - widths for single-mode Lorentz laser pulse and multi-mode Gauss laser pulse with line band 0.03, 0.08cm^{-1} respectively.

In general there is a physically reasonable agreement between theory and high-qualitative experiment. The detailed analysis shows that the shift and width of the multi-photon resonance line for interaction of atomic system with multimode laser pulse is greater than the shift and width for a case of interaction between atom and 1-mode laser pulse. This is entirely corresponding to the experimental data by Lompre et al [15]. Further we consider two-photon ionization for the Mg. The detailed analysis and state of art for this atoms had been considered, for example in Ref. [8,16]. In table 1 we present results of calculating characteristics of $3p^{21}S_0$ Mg resonance; E - energy, counted from ground state (см$^{-1}$), Г-autoionization width (см$^{-1}$), s/I - maximum generalized cross-section (см^{4}W^{-1}).

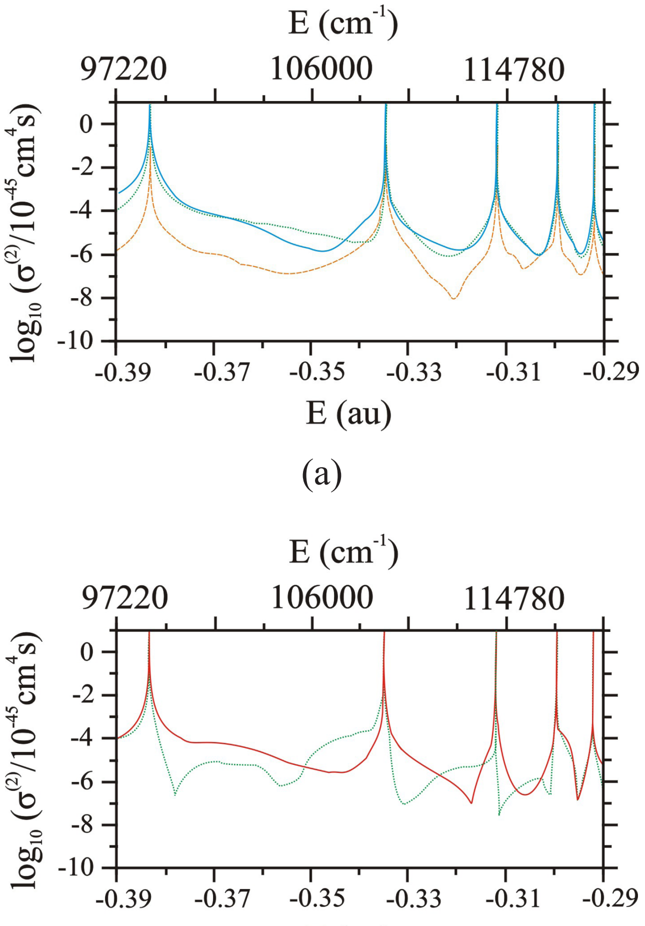
Table 1.

Characteristics for $3p^{21}S_0$ resonance of atom of the magnesium: *E* - energy, counted from ground state (см$^{-1}$), *Г* - autoionization width (см$^{-1}$), *σ/I* - max generalized cross-section (см^{4}W^{-1})

Methods	*E*	*Г*	*σ/I* (10^{-27})
Experiment	68273	280	
Luc-Koenig E. etal, 1997	Without	account	SE
Length form	68492	374	1.96
Velocity form	68492	376	2.10
Luc-Koenig E. etal, 1997	with	account	SE
Length form	68455	414	1.88
Velocity form	68456	412	1.98
Moccia and Spizzo (1989)	68320	377	2.8
Glushkov et al (2008)	68281	323	2.0
Robicheaux and Gao (1993)	68600	376	2.4
Mengali and Moccia (1996)	68130	362	2.2
Karapanagioti et al (1996)	68470	375	2.2
This work	68268	316	1.9

Note: screening effects (SE)

Note that the following methods have been used in computing characteristics for $3p^{21}S_0$ resonance: relativistic R-matrix method (R-метод; Robicheaux-Gao, 1993; Luc-Koenig E. etal, 1997), added by multi-channel quantum defet method, K-matrix method (К-method; Mengali-Moccia,1996), different versions of the finite L^2 method (L^2 method) with account of polarization and screening effects (SE) (Moccia-Spizzo, 1989; Karapanagioti et al, 1996), Hartree-Fock configuration interaction method (CIHF), operator QED PT (Glushkov et al 2008). It should be noted that the R-matrix calculation with using length and velocity formula led to results, which differ on 5-15%, that is evidence of non-optimality of atomic basis's. This problem disappears on our approach as the gauge-invariant scheme is used [12]. In figure 3 we present our data on energy dependences of the partial cross–sections $\sigma^{(2)}$ (in units $cm^4 \cdot s$) corresponding to ionization in the $3s\varepsilon s$ $J=0^e$, $3s\varepsilon d$ $J=2^e$, $3p\varepsilon p$ $J=0^e$ or $J=2^e$, and $3p\varepsilon f$ $J=2^e$ continua for the final states in the energy range 92220-119170 cm^{-1}. The obtained results are in physically reasonable agreement with data [8,17].



(a)

(b)

Figure 3. The ground state two-photon ionization for final states above the Mg+ 3p threshold (Partial generalized cross-sections – our data): (a) $J=2^e$ generalized cross-section; Partial cross-sections corresponds to ionization in the $3s\varepsilon d$ (blue line), $3p\varepsilon p$ (green line) and $3p\varepsilon f$ (yellow line). (b) $J=0^e$ generalized cross-section; Partial cross-sections corresponds to ionization in the $3s\varepsilon s$ (red line), $3p\varepsilon p$ (green line).

Further we present the results of the numerical simulation for the three-photon resonant, four-photon ionization profile of atomic krypton (the $4p \to 5d[1/2]_1$ and $4p \to 4d[3/2]_1$ three photon Kr resonances are considered). In Ref. [16] it has been performed the experimental studying the resonant multiphoton ionization of krypton by intense uv (285-310 nm) laser radiation for the intensity range 3×10^{12}-10^{14} W/cm^2. The experiment consisted of the measurement of the number of singly charged Kr and Xe ions produced under collisionless conditions as a function of laser frequency and intensity. The output of a dye-laser system operating at 2.5 Hz is frequency doubled in a 1-cm potassium dihydrogen phosphate (KDP) crystal to give a 0.5-mJ, 1.3-ps, transform-limited 0.1-nm-bandwidth beam tunable between 285 and 310 nm. There have been determined the corresponding parameters of the $4p \to 5d[1/2]_1$ (i) and $4p \to 4d[3/2]_1$ (ii) three photon Kr resonances. The resonance shift is proportional to intensity with a width dominated by lifetime broadening of the excited state. The corresponding shift and width have been found as follows: (i) the shift $\delta\omega_0(p\alpha|3)=aI$, $a_{exp}=3.96$ meV/(Tw·cm^{-2}); width $b_{exp}= 1.4$ meV/(Tw·cm^{-2}); (ii) shift $d\omega_0(p\alpha|3)=aI$, $a_{exp}=8.0$ meV/(Tw·cm^{-2}); width $b_{exp}=4.0$ meV/(Tw·cm^{-2}). The authors [16] have used quite simple model of an effective two-level atom with the assumption of a rate limiting three-photon excitation step followed by rapid one-photon ionization from the excited state. As expected, the three-photon resonances broaden and shift further as the laser pulse intensity is increases. The important feature of the corresponding profiles is linked with available asymmetry. Naturally, it is easy to understand that the asymmetric profile is typical of realistic laser pulses with the spatially and temporally varying intensity. Besides, the authors of Ref. [16] have noticed that while all resonances are "blue" shifted, ac Stark shift calculations, which are difficult to perform for excited states lead to both "blue" and " red" shifts. Our numerical simulation results for the $4p \to 5d[1/2]_1$ (i) and $4p \to 4d[3/2]_1$ (ii) three photon Kr resonances are as follows: (i) the shift $\delta\omega_0(p\alpha|3)=aI$, $a_{exp}=3.95$ meV/(Tw·cm^{-2}) and width $b_{exp}=$ 1.5 meV/(Tw·cm^{-2}); (ii) shift $\delta\omega_0(p\alpha|3)=aI$, $a_{exp}=8.05$ meV/(Tw·cm^{-2}) and width $b_{exp}=4.1$ meV/(Tw·cm^{-2}). This is in the physically reasonable correlation with the estimates [16] and experimental data. Analysis shows that the shift and width of the multi-photon resonance line for the interaction “atom- multimode laser pulse” is greater than the corresponding shift and width for a case of the “atom- single-mode pulse” (the Lorenz pulse model) interaction. From the physical point of view it is obviously provided by action of the photon-correlation effects and influence of the laser pulse multi-modity [7,8,9,15]. A great interest represents the possibility of the quantitative construction of the corresponding resonances profiles with explanation of the asymmetric nature by means calculating sufficiently “large” number of the multiphoton transition line moments.

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SPECTROSCOPY OF ATOMS IN A STRONG LASER FIELD: NEW METHOD TO SENSING AC STARK EFFECT, MULTIPHOTON RESONANCES PARAMETERS AND IONIZATION CROSS-SECTIONS

V. V. Buyadzhi, A. V. Glushkov, V. F. Mansarliysky, A. V. Ignatenko, A. A. Svinarenko

Odessa State Environmental University, L’vovskaya str.15, Odessa-16, 65016, Ukraine

Summary

The resonant multiphoton resonances shifts and widths and ionization cross-sections for multielectron atoms in a intense laser radiation field are studied. It is carried out a new consistent approach to atom in a strong realistic laser field, based on the relativistic energy formalism (S-matrix adiabatic formalism), relativistic Dirac equation Green function method and relativistic many-body perturbation theory with the Dirac-Kohn-Sham zeroth approximation. In relativistic theory, the Gell-Mann and Low adiabatic formula for energy shift is connected with electrodynamical scattering matrice, which includes interaction with as a laser field as a photon vacuum field (radiative decay). The optimized basis of the relativistic orbitals is generated with using a minimization procedure for the gauge-non-invariant contribution (the fourth-order of the QED perturbation theory) to the radiation width of atomic state. An approach to treating the multiphoton atomic processes is outlined on example of H, Cs, Kr,Mg etc. Analysis shows that the shift and width of the multi-photon resonance line for the interaction “atom- multimode laser pulse” is greater than the corresponding shift and width for a case of the “atom- single-mode pulse” (the Lorenz pulse model) interaction. From the physical point of view it is naturally provided by action of the photon-correlation effects and influence of the laser pulse multi-modity.

Keywords: laser field, sensing multiphoton resonances, energy approach, Green function method

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СПЕКТРОСКОПІЯ АТОМІВ В СИЛЬНОМУ ЛАЗЕРНОМУ ПОЛІ: НОВИЙ МЕТОД ВИЗНАЧЕННЯ ПАРАМЕТРІВ АС ЕФЕКТУ ШТАРКА, БАГАТОФОТОННИХ РЕЗОНАНСІВ ТА ПЕРЕРІЗІВ ІОНІЗАЦІЇ

В. В. Буяджи, О. В. Глушков, В. Ф. Мансарлійський, Г. В. Ігнатенко, А. А. Свинаренко

Одеський державний екологічний університет, вул. Львівська, 15, Одеса, 65016, Україна

Реферат

В роботі досліджуються теортично характеристики багатофонних процесів в атомах в полі інтенсивного лазерного випромінювання, , зокрема, зсув та ширина, резонансів, переріз іонізації. Запропоновано новий послідовний підхід в спектроскопії атому в сильному реалістичному лазерному полі, оснований на релятивістському енергетичному формалізмі

(S-матричний адіабатичний формалізм), методі релятивістської функції Гріна рівняння Дірака і релятивістській теорії збурень с Dirac-Kohn-Sham нульовим наближенням. У релятивістській теорії, адіабатична формула Гелл-Манн і Лоу для зсуву енергії пов'язана з електродинамічною матрицею розсіювання, яка включає в себе взаємодію як з полем лазерного випромінювання , так й полем вакуумного вакуума (радіаційний розпад). В методі використується опетимізовані базиси релятивістських орбіталей, які генеруються за допомогою процедури мінімізації калібрувально-неінваріантних (четвертий порядку КЕД теорії збурень) внесків в радіаційну ширину атомного стану. Підхід застосовано до кількісного розгляду багатофотонних процесів в атомах H, Cs, Kr,Mg та інших. Аналіз показує, що ззсув і ширина лінії багатофотонного резонансу при взаємодії атома з багатомодовим лазерним імпульсом (гаусова форма імпульсу) більше, ніж відповідний зсув і ширина у випадку взаємодії атома з лазерним імпульсом лоренцевої форми. З фізичної точки зору це, природно, забезпечується дією фотон-кореляційних ефектів і впливом модовой структури імпульсу лазерного випромінювання.

Ключові слова: лазерне поле, багатофотонні резонанси, енергетичний формалізм, метод функції Гріна