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Thermalized plasma of o-and f-like multicharged ions as an object for observation of new laser-electron nuclear effects

A possibility of the experimental observation of set of the electron satellites in spectra of the electron-nuclear g-transition of the nucleus in a multicharged atomic ion is analysed. It is proposed to use for observation of these effects the thermalized plasma of O-,F-like multicharged ions. As example, the nuclear transition in the isotope ${}^{57}_{26}Fe$ with energy 14,41 keV is considered for O-and F-like ions of Fe. It is shown that the electron-nuclear lines in spectra of emission or absorption can be experimentally observed in plasma of the O-and F-like multicharged ions and it is very important that they are not overlapping by the Doppler broadening.

In last years a great attention is turned to problems of experimental and theoretical study of high temperature multi-charged ions plasma and developing the new diagnostics methods (c.f. [1-28]). Similar interest is also stimulated by importance of carrying out the approaches to determination of the characteristics for multi-charged ions plasma in thermonuclear reactors, searching new mediums for X-ray range lasers [5-17]. A great progress in development of laser technique and accelerators experiments resulted to a new class of problems in the plasma physics and correspondingly diagnostics of their parameters [26-28]. Here it should be noted a possibility of the cooperative dynamical phenomena (c.f.[1-14]) due the interaction between atoms, ions, molecule electron shells and nuclei nucleons. In ref. [15-17] it has been estimated an influence of the electron shell on velocity of re-charging of the metastable nucleus and shown that this effect is very little one. Attractive situation arises under transition to heavy multicharged ions because of changing the energy and geometric parameters of electron shell. In result a character of interaction with a nucleus may strongly change and new channels of electron-nuclear processes are opened [23-28]. To traditional channels of the nucleus excited state decay there are added such effects as the electron-positron pair production (during the nucleus recharging) with output of new electron on free bound state. It is easily imagine a situation when this process becomes to be energetically possible only after removing the strongly bound electron in the initial state. A new class of problems here is to be considered as follows [27,28]: i). relativistic calculation of the the mixed γ- optical quantum transitions; ii).use of this effect in nuclear–atomic-molecular studies with use of lasers; iii).spectroscopy of γ resonances, creation of additional satellites and narrow resonances inside the Doppler contour of γ-line; iv).governing by the intensity of the complicated γ-transitions due to the changing of the molecular excited states population under action of laser radiation; v). relativistic quantum calculations of the complex "laser-electron-nuclei" systems.

A principally new approach to problem of the multi charged ions plasma diagnostics is provided by using the new laser-electron-nuclear spectral effects. In ref. [27-28] a consistent QED perturbation theory approach is developed and applied to calculation of the electron-nuclear γ transition spectra of nucleus in the multicharged ion. The intensities of satellites are defined in the relativistic version of the energy approach (S-matrix formalism). Decay and excitation probabilities are linked with imaginary part of the energy of the 'nuclei nucleons-electron shells-field' system. As example, the nuclear transition in the isotope ${}^{57}_{26}Fe$ with energy 14,41 keV is considered. The results of the relativistic calculation for the electron-nuclear γ-transition spectra (set of electron satellites) of the nucleus in a multicharged atomic ion *Fe*XIX were presented. It is of a great importance to discuss the possible experimental observation of indicated effects. As indicated in ref. [15-17,7,9] in neutral atoms under standard experimental conditions the intensive satellites are overlapping by the Doppler contour of the γ- radiation line. For their observation one should use the methods of inside-Doppler spectroscopy (c.f.[15]). In principle it is possible an observation of the satellites in the spectrum of emission or absorption without overlapping by the Doppler contour of the γ line. Such a situation could be realized in plasma of multicharged ions. In this paper we will evaluate the possibilities of such experiment realization.

Let us remember that the nuclear emission or absorption spectrum of the atom possesses a set of electron satellites, which are due to an alteration of the state of the electron shell [26-28]. The mechanism of formation of the satellites in neutral atoms and highly charged ion is different. In the first case (loose electron shell) a "shaking of the shell resulting from the interaction between the nucleus and γ quantum is predominant. In the second case (rigid electron shell) the mechanism involves a direct interaction between γ quantum and electrons. The second mechanism is important in the case of dipole nuclear transitions and dominates at γ quantum energies ≤ 4 z keV (z is effective nuclear charge). The traditional selection rules and familiar intensity hierarchy with respect to electron transition multiplicity do not pertain to the second mechanism. Consequently, the satellite spectrum is much enriched and transitions between the fine and hyper fine structure components, 0-0 transitions and transitions which do not involve a change in the electron configuration can be considered. The main effect of arising the electron satellites for nuclear transitions has an kinematics nature, which is in the shifting the system mass centre under emission of the γ-quanta relatively of the proton or electron orbital. The intensities of satellites lines are theoretically defined by the imaginary part of excited state energy for three-quasi-particle system (rigid nuclear core="c", above core proton ="p" and electron ="e") as a sum of the core, proton and electron contributions:

$$\mathrm{Im}\,E = \mathrm{Im}\,Ec + \mathrm{Im}\,Ep + \mathrm{Im}\,Ee,$$

$$\mathrm{Im}\,Ea = -Z_a^2 / 4\pi \sum_F \iint dr_{c1} dr_{c2} \iint dr_{p1} dr_{p2} \iint dr_{+1e1} dr_{e2} \Phi_I^*(1) \Phi_F^*(2) \cdot$$

$$\cdot T_a(1,2) \Phi_F(1) \Phi_I(2), \tag{1}$$

$$T_a(1,2) = \sin(w_{IF} r_{a12}) / r_{a12} \{1/M \mu_a (\nabla_{ra1}, \nabla_{ra2}) + 1\},$$

where $r_{a12} = |r_{a1} - r_{aa2}|$; Φ_c, Φ_p, Φ_e are the secondly quantified operators of field of the core particles, the fields of protons and the field of electrons. The sum on F designs the summation on the final states of system. In the second QED perturbation theory order, the full width of level is divided on the sum of the partial contributions, connected with the radiation decay into concrete final states of system. These contributions are proportional to the probabilities of the corresponding transitions. The system of the red (blue) satellites corresponds to the transitions with excitement (de-excitement) of the electron shell. The matrix elements in above written expressions are calculated on the relativistic solutions of the Dirac equation whose radial part is represented by

$$F' = -F(æ + |æ|)/r - G(E + 2M\tilde{\alpha}^{-2} - V)\tilde{\alpha},$$

$$G' = G(æ - |æ|)/r + F(E - V)\tilde{\alpha} \tag{2}$$

where æ is the Dirac quantum number, E-the state energy, F, G being the large and small radial components correspondingly. The procedure details for definition of contributions in (1) and corresponding matrix elements are described in refs. [23-28].

As it is above indicated, in principle it is possible an observation of the satellites in the spectrum of emission or absorption without overlapping by the Doppler contour of the γ- radiation line. Such a situation may be realized in the thermalized plasma of multicharged ions. It is supposed that the K shell is significantly destroyed. According to [26,27], an average kinetic energy for ions in a such plasma: $\sim E_i/10 \sim 1/20$ c.u. (coulomb units), where E_i is the "*1s*" electron bond energy. The Doppler shift is as follows: $\delta h\omega_D \quad \alpha\omega/(10M)^{1/2}$ .The value αω of is connected with the of γ quantum by the following relation: $E\gamma$/keV] $\quad 4Z(\alpha\omega)$; If, say, $\alpha\omega = 1$, then $\delta h\omega_D \quad 1/200\,(Z)^{1/2}$ c.u. $0{,}15\,(Z)^{1/2}$ eV. For comparison let us give the values of the 1s,2s,2p-2p electron transitions for one-electron ions with Z=10-50: $E(1s\text{-}2p_{3/2)}$=1,3·10^3-2,3·10^4eV, $E(2s\text{-}2p_{3/2)}$ $E(2s\text{-}2p_{3/2)}$==0,1-3,3·10^2eV. As it has been seen the transition energies have an order of the Doppler shift value. The little value of splitting in the one-electron ions is entirely provided by relativistic corrections. In a multi-electron system a situation is more favourable. Here we consider a case of the O-like and F-like multicharged ions. An additional splitting is defined by inter electron interaction. In table we present the energies of levels for L shell of the oxygen-like ion *Fe*XIX (Z=26) [24] , counted from the ground level $2s^2 2p^2\,{}^3P_2$.

Configuration	$2s^22p^4$				$2s^22p^5$				$2p^6$
State	$^3P_0$	$^3P_1$	$^1D_2$	$^1S_0$	$^3P_2$	$^3P_1$	$^3P_0$	$^1P_1$	$^1S_0$
E, eV	9,7	11,5	21,3	40,7	114,6	122,3	127,9	157,6	265,1

The lines of big number of the electron satellites, connected with 2-2 transitions are sufficiently far from the Doppler contour. As in ref .[26,27] we consider the nuclear transition in the isotope $^{57}_{26}Fe$ with the quantum energy 14,41 keV. The period of the half decay of state $T(1/2)$=9,77 10^{-8} s , the recoil energy 1,96 10^{-6} keV, the parameter $\alpha\omega$=0,27.We consider the following transitions: *1s-2s* (monopole), $1s\text{-}2p_{1/2}$, $2s\text{-}2p_{3/2}$ (dipole), $2p_{1/2}\text{-}2p_{3/2}$ (quadruple). Let us consider a scheme of disposition for some electron satellites in relation to the nuclear transition line for the *O*-and *F*-like ions . Satellites connected with the 1-2 transitions are separated from $\omega_0\gamma$ on value 6 keV, but their intensity is less. In fig.1 there are presented the lines which are accompanied by electron transitions: *1* - $2s^22p^{4\,1}S_0\text{-}2s2p^{5\,3}P_1$; *2* - $2s^22p^{4\,3}P_1\text{-}2s2p^{5\,3}P_2$; *3* - $2s^22p^{4\,3}P_2\text{-}2s2p^{5\,3}P_1$; *4* - $2s2p^{5\,3}P_1\text{-}2p^{6\,1}S_0$. The relative intensities for these satellites are $7\cdot10^{-5}$, the Doppler broadening is $\delta h\omega_D$ 5 эВ (shown on figure qualitatively). So, it is clear that the electron-nuclear lines in spectra of emission or absorption can be experimentally observed in plasma of O-and F-like multicharged ions and they are not overlapping by the Doppler broadening.

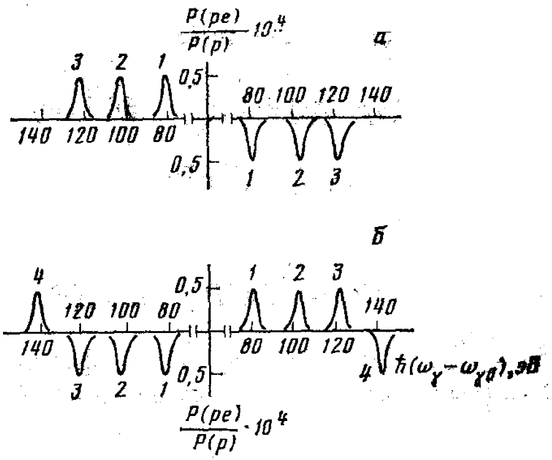

Figure. The positions of emission and absorption lines electron satellites (in a positive and negative direction of abscissa axe correspondingly) for ions *Fe*XIX, *Fe* XVIII in lowest states of the ground configurations $2s^22p^4$, $2s^22p^5$ (a) and states of the excited configuration $2s2p^5$, $2s2p^5nl$ (b) relatively the nuclear γ-transition in isotope of $^{57}_{26}$Fe with energy $h\omega_0\gamma$=14,41 keV [26-28]; *P(pe)/P(p)* is relation of the satellite intensity to the nuclear transition line intensity.

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С. В. Малиновская

Термализованная плазма о-и f-подобных многозарядных ионов как объект для наблюдения новых лазерно-электрон-ядерных эффектов

АННОТАЦИЯ

Проанализированы возможности наблюдения системы электронных сателлитов в спектре электрон — ядерных γ переходов в ядре многозарядного иона. Предлагается использовать для наблюдения искомых эффектов термализованную плазму О- и F- подобных многозарядных ионов. В качестве примера рассматривается переход в изотопе $^{57}_{26}Fe$ с энергией 14,41 kэВ. Показано, что электрон — ядерные линии в спектре излучения или поглощения могут быть экспериментально обнаружены в плазме О- и F- подобных многозарядных ионов, причем искомые линии не перекрываются уширением Доплера.

С. В. Малиновська

Термалізована плазма о- та f-подібних багатозарядних іонів як об'єкт для спостерігання нових лазерно-електрон-ядерних ефектів

АНОТАЦІЯ

Проаналізовані можливості спостерігання системи електроних сателітів у спектрі електрон — ядерних γ переходів в ядрі багатозарядного іону. Запропоновано використати для спостерігання шуканих ефектів термалізовану плазму О- і F- подібних багатозарядних іонів. Як прикл\ад, розглянуто перехід в ізотопі $^{57}_{26}Fe$ з енергією 14,41 kэВ. Показано, що електрон — ядерні лінії у спектрі випромінювання або поглинення можуть бути експеріментально спостережені у плазмі О-, F- подібних багатозарядних іонів, при чому шукані лінії не перекриваються уширюванням Доплера.