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SPECTROSCOPY OF MULTICHARGED IONS IN PLASMAS: OSCILLATOR STRENGTHS OF Be-LIKE ION Fe

The generalized relativistic energy approach with using the Debye shielding model is used for studying spectral parameters of ions in plasma and determination of the oscillator strengths for the Be-like ions. An electronic Hamiltonian for N-electron ion in a plasma is added by the Yukawa-type electron-electron and nuclear interaction potential. Oscillator strengths gf for $2s^2$-$[2s_{1/2}2p_{3/2}]_1$ transition in Be-like Fe are computed for different values of the electron density and temperature (n_e=10^{22}-10^{24}cm^{-3}, T=0.5-2 keV) of plasmas are presented and compared with available alternative spectroscopic data.

1. Introduction

Spectroscopy of multicharged ions in a plasmas is one of the most fast developing branches of modern atomic spectroscopy. Let us remind that a great interest to studying radiation and collision processes parameters in a plasmas is connected with importance of these data for correct description of parameters characteristics for plasma in thermonuclear (tokamak) reactors, searching new mediums for X-ray range lasers [1-20]. In many papers the calculations of various atomic systems embedded in Debye plasmas have been performed ([13-16]). Different theoretical methods were employed along with the Debye screening to study plasma medium. Earlier we have developed a new version of a relativistic energy approach combined with the many-body perturbation theory (RMBPT) for multi-quasiparticle (QP) systems for studying spectra of plasma of the multicharged ions and electron-ion collisional parameters. The method is based on the Debye shielding model and energy approach [16-22]. A new element of this paper is in using the effective optimized Dirac-Kohn-Sham method in general relativistic energy approach to collision processes in the Debye plasmas. Here Oscillator strengths gf for $2s^2$-$[2s_{1/2}2p_{3/2}]_1$ transition in Be-like Fe are computed for different values of the electron density and temperature (n_e=10^{22}-10^{24}cm^{-3}, T=0.5-2 keV) of plasmas are presented and compared with available alternative spectroscopic data.

2. Generalized energy approach in scattering theory. Debye shielding model

Let us firstly consider the Debye shielding model accordinf to Refs. [16,18]. It is known (see [10-14,19] and refs. therein) in the classical theory of plasmas developed by Debye-Hückel, the interaction potential between two charged particles is modelled by the Yukawa-type potential, which contains the shielding parameter m [1]. The parameter m is connected with the plasma parameters such as the temperature T and the charge density n as follows: $\mu \sim \sqrt{e^2 n / k_B T}$. Here, as usually, e is the electron charge and κ_B is the Boltzman constant. The density n is given as a sum of the electron density N_e and ion density N_k of the k-th ion species having the nuclear charge q_k : $n = N_e + \sum_k q_k^2 N_k$. Under typical laser plasma conditions of T~1keV and n~10^{22} cm^{-3} the parameter m is of the order of 0.1 in atomic units [13,14]. By introducing the Yukawa-type e-N and e-e interaction potentials, an electronic Hamiltonian for N-electron ion in a plasma is in atomic units as follows [19]:

$$H = \sum_i [\alpha cp - \beta mc^2 - Z\exp(-\mu r_i)/r_i] + \\ + \sum_{i>j} \frac{(1-\alpha_i\alpha_j)}{r_{ij}} \exp(-\mu r_{ij}) \quad (1)$$

The generalized relativistic energy approach combined with the RMBPT has been in details described in Refs. [19-22]. It generalizes earlier developed energy approach [5-8]. The key idea is in calculating the energy shifts DE of degenerate states that is connected with the secular matrix M diagonalization [4-6]. To construct M, one should use the Gell-Mann and Low adiabatic formula for DE. The secular matrix elements are already complex in the PT second order. The whole calculation is reduced to calculation and diagonalization of the complex matrix M .and definition of matrix of the coefficients with eigen state vectors $B^K_{v,v}$ [5-8]. To calculate all necessary matrix elements one must use the basis's of the 1QP relativistic functions. Within an energy approach the total energy shift of the state is usually presented as [3-7]:

$$\Delta E = \mathrm{Re}\Delta E + \mathrm{i}\, \Gamma/2 \quad (2)$$

where G is interpreted as the level width and decay possibility $P = G$. The imaginary part of electron energy of the system, which is defined in the lowest PT order as [3]:

$$\mathrm{Im}\Delta E(B) = -\frac{e^2}{4\pi} \sum_{\substack{\alpha>n>f \\ [\alpha<n\le f]}} V^{|\omega_{\alpha n}|}_{\alpha n \alpha n}, \quad (3)$$

where $\sum_{\alpha>n>f}$ for electron and $\sum_{\alpha<n\le f}$ for vacancy. The separated terms of the sum in (3) represent the contributions of different channels and a probability is:

$$\Gamma_{\alpha_n} = \frac{1}{4\pi} \cdot V^{|\omega_{\alpha n}|}_{\alpha_n \alpha_n} \quad (4)$$

Which is linked with an oscillator strength by the standard way. It is known that their adequate description requires using the optimized basis's of wave functions. In [6] it has been proposed "ab initio" optimization principle for construction of cited basis's. It uses a minimization of the gauge dependent multielectron contribution of the lowest QED PT corrections to the radiation widths of atomic levels. This contribution describes collective effects and it is dependent upon the electromagnetic potentials gauge (the gauge non-invariant contribution dE_{minv}). The minimization of ImdE_{minv} leads to integral differential equation, that is numerically solved. In result one can get the optimal one-electron basis of the PT [21-23]. It is worth to note that this approach was used under solvin of multiple problems of modern atomic , nuclear and molecular physics (see [23-67]). To generate the wave functions basis we use the optimized Dirac-Kohn-Sham potential with one parameter [8], which calibrated within the special ab initio procedure within the relativistic energy approach [6]. The modified PC numerical code 'Superatom" is used in all calculations. Other details can be found in Refs. [5-9, 16-22].

3. Results and conclusion

Firstly, we present our results on energy shifts and oscillator strengths for transitions $2s^2$-$2s_{1/2}2p_{1/2,3/2}$ in spectra of the Be-like Fe. The corresponding plasma parameters are as follows: n_e=10^{22}-10^{24}cm^{-3}, T=0.5-2 keV (i.e. m~0.01-0.3). We studied a behavior of the energy shifts DE (cm^{-1}) for $2s^2$-$[2s_{1/2}2p_{1/2,3/3}]_1$ transitions and oscillator strengths changes for different plasma parameters (the electron density and temperature). In Table 1 there are listed the oscillator strengths gf for $2s^2$-$[2s_{1/2}2p_{3/2}]_1$ transition in Be-like Fe for different values of the n_e (см$^{-3}$) and T (in eV).

Table 1

Oscillator strengths for $2s^2$-$[2s_{1/2}\,2p_{3/2}]_1$ transition in Be-like Fe for different n_e (см$^{-3}$) and T (eV) (gf_0 –gf value for free ion)

n_e		10^{22}	10^{23}	10^{24}
kT	[13]	[13]	[13]	[13]
500	0.1537	0.1537	0.1538	0.1547
1000		0.1537	0.1538	0.1545
2000		0.1537	0.1538	0.1543

Продовження таблиці 1

2000		0.1555	0.1556	0.1562
I-S		0.1537	0.1537	0.1540
		0.1555	0.1555	0.1559
n_e		10^{22}	10^{23}	10^{24}
kT	Our	Our	Our	Our
500	0.1541	0.1541	0.1543	0.1553
1000		0.1541	0.1543	0.1553
2000		0.1540	0.1542	0.1552
2000		0.1541	0.1542	0.1552

There are also listed the available data by Li etal and Saha-Frische: the multiconfiguration Dirac-Fock (DF) calculation results, and ionic sphere (I-S) model simulation data [13, 16] (see refs. therein). The analysis shows that the presented data are in physically reasonable agreement, however, some difference can be explained by using different relativistic orbital basises and different models for accounting of the plasma screening effect. It is important to note that our computing oscillator strengths within an energy approach with different forms of transition operator (this is corresponding to using the photon propagators in the form of Coulomb, Feynman and Babushkin) gives very close results.

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Summary

The generalized relativistic energy approach with using the Debye shielding model is used for studying spectral parameters of ions in plasma and determination of the oscillator strengths for the Be-like ions. An electronic Hamiltonian for N-electron ion in a plasma is added by the Yukawa-type electron-electron and nuclear interaction potential. Oscillator strengths gf for $2s^2$-$[2s_{1/2}2p_{3/2}]_1$ transition in Be-like Fe are computed for different values of the electron density and temperature ($n_e=10^{22}$-$10^{24}cm^{-3}$, T=0.5-2 keV) is presented and compared with available alternative spectroscopic data.

Key words: spectroscopy of ions in plasmas, relativistic energy approach, oscillator strengths

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СПЕКТРОСКОПИЯ МНОГОЗАРЯДНЫХ НОНОВ В ПЛАЗМЕ: СИЛЫ ОСЦИЛЛЯТОРОВ ДЛЯ Be-ПОДОБНОГО НОНА Fe

Резюме

На основе обобщенного релятивистского энергетического подхода с использованием модели экранирования Дебая выполнено изучение спектра плазмы ионов и определение сил осцилляторов для Be-подобных ионов. Электронный гамильтониан для N-электронного иона в плазме дополнен потенциалом электрон-электронного и ядерного взаимодействия типа Юкавы. Силы осцилляторов $2s^2$-$[2s_{1/2}2p_{3/2}]_1$ перехода в Be-подобном Fe определены для различных значений электронной плотности и температуры ($n_e=10^{22}$-$10^{24}cm^{-3}$, T=0.5-2 keV) плазмы и сравниваются с имеющимися альтернативными спектроскопическими данными. .

Ключевые слова: спектроскопия ионов в плазме, энергетический подход, силы осцилляторов

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СПЕКТРОСКОПІЯ БАГАТОЗАРЯДННХ ІОНІВ В ПЛАЗМІ: СИЛИ ОСЦИЛЯТОРІВ ДЛЯ Be-ПОДІБНОГО ІОНА Fe

Резюме

На основі узагальненого релятивістського енергетичного підходу з використанням моделі екранювання Дебая виконано вивчення спектру плазми іонів і визначення сил осциляторів для Be-подібних іонів. Електронний гамильтоніан для N-електронного іона в плазмі доповнений потенціалом електрон-електронної та ядерної взаємодії типу Юкави. Сили осциляторів $2s^2$-$[2s_{1/2}2p_{3/2}]_1$ переходу в Be-подібному Fe визначені для різних значень електронної густини і температури ($n_e=10^{22}$-$10^{24}cm^{-3}$, T=0.5-2 keV) плазми та порівнюються з наявними альтернативними спектроскопічними даними.

Ключові слова: спектроскопія іонів в плазмі, енергетичний підхід, сили осциляторів