UDC 539.181, 539.184

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THE BETA ELECTRON FINAL STATE INTERACTION EFFECT ON BETA DECAY PROBABILITIES FOR ^{42}Se NUCLEUS WITHIN RELATIVISTIC HARTREE-FOCK APPROACH

Contributions of final states interaction of the beta electrons into the b decay characteristics for the super allowed transition $O^+ \to O^+$ in nucleus of ^{42}Se is carried out within the relativistic Hartree-Fock approach.

Paper is devoted to calculating contributions of the final states interactions of the beta electrons into the b decay characteristics for the super allowed transition $O^+ \to O^+$ in nucleus of ^{42}Se with using the relativistic Hartree-Fock (RHF) method (Cowan version). Earlier this problem has been considered with using the new theoretical, optimized gauge invariant Dirac-Fock (GIDF) approaches [1—4]. Let us know that the study of the β decay processes attracts a great interest especially due to the new experimental studies of the β decay for the number of nuclei [2—12]. One can mention that the disagreement between different experimental data regarding the β-decay in heavy radioactive nuclei is provided by different chemical environment influence of radioactive nucleus and this effect over the different chemical compounds differs from each other. In ref. [1, 4, 5, 10, 12] the cited disagreement in data on the half-decay period for the number of isotopes (c. f. [5, 10, 12]) is explained by existence of the special beta decay channel, influence of atomic chemical environment on the beta decay, by action of so-called cooperative electron-nuclear effects. More detailed description of chemical bond effect is given in ref. [1—4]. The final state interaction of the beta electrons and related phenomena are the other effects, which is usually not accounted for. In ref. [9] the effect of interaction in the final state between beta electron and atomic electrons with the accuracy to $(\alpha Z/v)^2$ in the first non-vanishing approximation has been calculated. In fact, this is a parameter of Coulomb interaction between beta electron and atomic bound electrons and v is the beta electron velocity. It is uncommon, that this contribution can be quite essential. In ref. [1, 4] contributions of final states interaction of the beta electrons into the b decay characteristics for the super allowed transition $O^+ \to O^+$ in nucleus of ^{42}Se is carried out within the new GIDF approach. It is well known that the standard approach to calculation of the beta decay characteristics is based on the usual non-relativistic Hartree-Fock or Hartree-Fock-Slater approach with account of the finite nuclear size. More correct calculation uses the relativistic approaches, in particular, the well known relativistic Hartree-Fock or DF method. In ref. [1—4] there are developed new ab initio schemes (GIDF and GI Dirac-Kohn-Sham schemes) to calculation of spectra, wave functions basis of the heavy elements with account of relativistic, correlation, nuclear, QED effects, based on gauge-invariant QED perturbation theory [13—18]. The account procedure of the nuclear finite size effects is taken from the cited references. In this paper we present the calculation results for contributions of the final states interactions of the beta electrons into the b decay characteristics. Cowan version of the relativistic Hatree-Fock methos is used in calculation [19, 20]. The results are presented for super allowed transitions $O^+ \to O^+$ for nucleus ^{42}Se.

According to refs. [1, 3, 10, 12], the distribution of the beta particles on energy in the permitted transitions is as follows:

$$dW_\beta(E)/dE = \frac{1}{2\pi^3} G^2 F(E,Z) Ep(E_0 - E)^2 \mid M \mid^2 . \quad (1)$$

Here G — weak interaction constant; E and $p = (E^2 - 1)^{1/2}$ — entire energy and pulse of beta particle; $E_0 = 1 + (E_{bn}/m_e c^2)$, E_{bn} — boundary energy of β-spectrum; $|M|$ — matrix element, which is not dependent upon an energy in case of the permitted β-transitions. As usually to calculate the β decay shape and decay half period one should use tables of Fermi function and integral Fermi function. Fermi function F and integral Fermi function f are defined as:

$$F(E,Z) = \frac{1}{2p^2}(g_{-1}^2 + f_{+1}^2), \quad (2a)$$

$$f(E_0,Z) = \int_1^{E_0} F(E,Z) Ep(E_0 - E)^2 dE. \quad (2b)$$

Here f_{+1} and g_{-1} — relativistic electron radial functions; the indexes $\pm l = \chi$, where $\chi = (l - j)/(2j + 1)$. Two schemes of calculation are usually used: i) the relativistic electron radial wave functions are calculated on the boundary of spherical nucleus with radius R_0 (it has done in ref. [10]); ii) values of these functions in the zero are used (see ref. [12]). The half decay period can be defined as follows: $T_{1/2} = 2\pi^3 \ln 2/[G^2 \ |M|^2 f(E_0, Z)]$.

The normalisation of electron radial functions f_i and g_i provides the behaviour of these functions for large values of radial valuable as follows:

$$g_i(r) \to r^{-1}[(E+1)/E]^{1/2} \sin(pr + \delta_i), \quad (3a)$$

$$f_i(r) \to r^{-1}(i/|i|)\,[(E-1)/E]^{1/2} \cos(pr + \delta_i). \quad (3b)$$

An effect of interaction in final state between beta electron and atomic electrons with the accuracy to $(\alpha Z/v)^2$ is manifested and further accounted for in the first non-vanishing approximation [4]. This contribution changes the energy distribution of the beta electron on value:

$$dW_\beta(E)/dE \Big/ dW_\beta^{(0)}(E)/dE =$$

$$= 1 - (\alpha E/p)^2 < \Psi_{in} \sum_j^z (a_B/|r_j|)\,|\Psi_{in}>,$$

where ψ_{in} — wave function of atom initial state, z is a number of electrons, a_B — Bohr radius.

To calculate relativistic atomic fields and electron wave functions, we have used Cowan version of RHF scheme. Its detailed description is given in ref. [19, 20]. RHF equations for N-electron system are written and contain the potential: $V(r) = V(r|nlj) + V_{ex} + V(r|R)$, which includes electrical and polarization potentials of the nucleus. The part V_{ex} accounts for exchange inter-electron interaction. Note that the procedure of the exchange account in RHF scheme is similar to one in the usual Hartree-Fock or DF approach. The rest exchange-correlation effects are accounted for in the first two QED perturbation theory orders by the total inter-electron interaction. The nuclear finite size effect is accounted for according to ref.[21]. Approach allows calculating the continuum wave functions with the entire exchange account of the continuum electron with electrons of the atom.

We have calculated atomic chemical environment and final state interaction effects on the b decays for super allowed transitions $O^+ \to O^+$ (nuclei: ^{42}Se). In table 1 we present our results for corrections ft to probability of the super allowed transitions $O^+ \to O^+$ due to final state interaction effect (FSI).

Table 1

Corrections to probability of the super allowed transitions $O^+ \to O^+$ due to final state interaction effect (FSI)

Nucl.	Compilated data (without FSI) [9]	Calculation with FSI [9]	Calculation with FSI [3]	Calc. with FSI Our data
^{42}Se	3089,3±7,5	3097,8	3095,4	3094,2

There are also presented the compiled data (without accounting for final state interaction effect) and the estimates from ref. [9] within Durand approach. Besides, the result of consistent DF calculation is also presented. FSI correction may not be directly defined in the heavy nuclei due to the great indefiniteness in nuclear matrix elements. Exception is the super allowed transition $O^+ \to O^+$. These transitions are used for definition of weak interaction constant $G_V(ft \sim G_V^2)$. As one can see there is quite significant difference between presented values for different calculation schemes. So, we can conclude that there is systematic defect in the existing theory of accounting corrections. An analysis shows that our data and results of ref. [3] can be considered as the most correct ones.

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ВЛИЯНИЕ ЭФФЕКТА ВЗАИМОДЕЙСТВИЯ В КОНЕЧНОМ СОСТОЯНИИ В ЭЛЕКТРОНА НА ВЕРОЯТНОСТЬ В РАСПАДА ДЛЯ ЯДРА ^{42}Se В РАМКАХ РЕЛЯТИВИСТСКОГО МЕТОДА ХАРТРИ-ФОКА

В рамках релятивистского метода Хартри-Фока рассчитан вклад в характеристики β распада эффекта взаимодействия в конечном состоянии β электрона. для сверхразрешенного перехода $O^+ \to O^+$ в ядре ^{42}Se.

УДК 539.181, 539.184

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ВПЛИВ ЕФЕКТУ ВЗАЄМОДІЇ У КІНЦЕВОМУ СТАНІ В ЕЛЕКТРОНУ НА ІМОВІРНІСТЬ В РОЗПАДУ ДЛЯ ЯДРА ^{42}Se В МЕЖАХ РЕЛЯТИВІСТСЬКОГО МЕТОДУ ХАРТРІ-ФОКА

У межах релятивістського методу Хартрі-Фока розраховано внесок у характеристики β розпаду за рахунок ефектів взаємодії у кінцевому стані β електрону для наддозволеного переходу $O^+ \to O^+$ у ядрі ^{42}Se.