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QUADRATIC BEHAVIOR OF Ft VALUES OF SUPERALLOWED FERMI BETA DECAYS

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ABSTRACT

In the present work, quadratic behavior of *Ft* values of the superalloved $0^+ \to 0^+$ Fermi beta transitions have been investigated by on the eleven well known superallowed Fermi Beta decays; the parent nuclei are ^{10}C, ^{14}O, ^{26}Al, ^{34}Cl, ^{38}K, ^{42}Sc, ^{46}V, ^{50}Mn, ^{54}Co, ^{62}Ga, ^{74}Rb. Broken isospin symmetry of shell model Hamiltonian has been restored by Pyatov method. Within the Random Phase Approximation (RPA), calculations have been performed considering without and with pairing interactions.

Keywords: *Superallowed Fermi beta decays, Ft values, isospin breaking.*

SÜPERİZİNLİ FERMİ BETA GEÇİŞLERİNİN Ft DEĞERLERİNİN KUADRATİK DAVRANIŞI

ÖZET

Bu çalışmada çok iyi bilinen ve ana çekirdekleri ^{10}C, ^{14}O, ^{26}Al, ^{34}Cl, ^{38}K, ^{42}Sc, ^{46}V, ^{50}Mn, ^{54}Co, ^{62}Ga, ^{74}Rb olan onbir süperizinli $0^+ \to 0^+$ Fermi beta geçişinin *Ft* değerlerinin kuadratik davranışı incelenmiştir. Kabuk model Hamiltoniyen'in kırılan izospin simetrisi Pyatov metodu kullanılarak düzeltilmiştir. Hesaplamalar rastgele faz yaklaşımı (RPA) çerçevesinde çift etkileşmeyi dikkate alarak ve almayarak yapılmıştır.

Anahtar Kelimeler: *Süperizinli Fermi beta geçişleri, Ft değerleri, izospin kırılması.*

1. INTRODUCTION

Superallowed beta decays are pure Fermi type transitions. Superallowed $J^\pi 0^+ \to 0^+$ Fermi beta decay in nuclei is a good tool in order to test results and predictions of the electroweak standard model. Transition occurs between two components of the same isospin multiplet *i.e.* between isobar analogue states and, the transition is the subject of various studies [1-14].

The Cabibbo-Kobayashi-Maskawa (CKM) matrix [15, 16] connects quark eigenstates of weak interaction with quark mass eigenstates,

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}, \tag{1}$$

which is unitary.

The superallowed Fermi beta decay is one of the few process to calculate the up and down quark mixtures amplitude (V_{ud}) of (CKM) matrix. Because of unitarity, the elements in the first row should verify condition [15, 16]:

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1. \tag{2}$$

Decays depend only on Fermi matrix element M_V , *i.e.* because the superallowed beta decays depend uniquely on vector part of the weak interaction, the Gammow-Teller matrix elements are defined as $M_A = 0$ [1, 17], and the ft value of Fermi beta transition is;

$$ft = \frac{K}{G_V^2 \left| M_V \right|^2}, \tag{3}$$

where $K/(\hbar c)^6 = 2\pi^3 \hbar \ln 2/(m_e c^2)^5 = (8120.271 \pm 0.012) \times 10^{-10}$ $GeV^{-4}s$, G_V is vector constant.

It is well known, for the Fermi beta transitions between $T = 1$ states, M_V 's ideal value is $\sqrt{2}$. Isospin symmetry is not exact in nuclei and, there is a discrepancy for the Fermi matrix element value. This discrepancy is defined as follows;

$$\left| M_V \right|^2 = 2(1 - \delta_C), \tag{4}$$

where δ_C is isospin symmetry breaking correction.

Nucleus dependent corrections should be obtained from experimental ft value. Introducing the correction terms, the experimental ft value can be expressed as follows;

$$Ft \equiv ft(1 + \delta_{\mathrm{R}})(1 - \delta_{\mathrm{C}}) = \frac{K}{2G_{\mathrm{V}}^2 (1 + \Delta_{\mathrm{R}}^{\mathrm{V}})}, \tag{5}$$

where f is statistical rate function, t is partial half-life for transition. Ft is named as "corrected Ft ". δ_R and Δ_R^V is nucleus-dependent part and nucleus-independent part of radiative correction, respectively. Radiative correction is separated into two terms:

$$\delta_{\mathrm{R}} = \delta_{\mathrm{R}}' + \delta_{\mathrm{NS}}. \tag{6}$$

The former is independent of nuclear structure while the latter depends on nuclear structure. Due to this separation, left side of the Eq. (3) becomes [17]

$$Ft \equiv ft(1+\delta'_{\mathrm{R}})(1+\delta_{\mathrm{NS}}-\delta_{\mathrm{C}}), \tag{7}$$

where the first correction term is independent of nuclear structure and the second term is related with structure.

Furthermore, the isospin symmetry breaking correction (δ_C) has been split in two terms,

$$\delta_C = \delta_{C1} + \delta_{C2}. \tag{8}$$

Here, δ_{C1} represents effect of the Coulomb and other charge dependent nuclear forces that cause configuration mixing among the 0^+ state wave functions in the parent and also daughter nuclei. δ_{C2} includes other effect of the Coulomb interaction.

In the electroweak theory, relationship between the Fermi and vector coupling constant is $G_V = G_F V_{ud}$. From the equations (5) and (7), the matrix element V_{ud} is given as [11]:

$$V_{ud}^2 = \frac{2984.38(6)}{Ft}, \tag{9}$$

and the Fermi coupling G_F is obtained from muon beta decay.

There are a few active groups focused on the investigation of isospin breaking correction of the superallowed beta decays and the CKM matrix unitarity. Towner and Hardy made many calculations for the value of isospin breaking correction terms using the shell model [2, 4, 5, 14]. Ormand and Brown also used the shell model and, Hartree-Fock (HF) calculations for the breaking terms [6,10]. Another method based on the formalism of R-matrix theory [7, 8]. The other work in which RPA correlations added to a HF calculation putting together charge symmetry and charge independence was conducted by Sagawa et al. [11]. A large shell model calculation was performed for the A=10 case by Navratil et al. [12].

Wilkinson also investigated to determine and eliminate the isospin breaking by appropriate extrapolation to $Z \approx 0$ looking to experimental data [9, 13] and, using the different particle data to search on the unitarity of the CKM matrix, successively [18-22].

In the mentioned studies above, the residual interaction was not related to the shell model potential in the self-consistent way; in fact such a relation is necessary since the meanfield potential includes isovector term.

In the present study, different from our previous works, quadratic behaviour of Ft values of the superallowed beta decays have been investigated both without and with pairing correlations based on Pyatov's method [23, 24] self-consistently. Pyatov method has been used several studies [24-33]. In our previous studies, the CKM matrix unitarity and Ft values of superallowed beta taransitions were investigated both without and with

pairing interactions in [34] and [35], respectively. Isospin admixtures and isospin structure of isobar analog resonance states of the superallowed beta decays calculations were also performed in Ref. [36].

The paper is organized as follows. In Section 2, the details of Pyatov method are given first. The calculated results and conclusions are then presented in Sections 3 and 4, respectively.

2. METHOD

As is well known, the single particle shell model potential is given by

$$U(r) = -U_0 f_0(r) + U_1 f_1(r) t_z + V_c(r) . \tag{10}$$

In Eq. (10), $f_0(r)$ and $f_1(r)$ are the radial functions of the isoscalar and isovector potentials, respectively, U_0 and U_1 are parameters and, $V_c(r)$ is Coulomb potential. Form of the Coulomb potential is

$$V_C = \sum_{k=1}^{A} v_c(k)\left(\frac{1}{2} - t_z(k)\right) \tag{11}$$

where

$$t_z = \begin{cases} \frac{1}{2} & for \quad neutrons, \\ -\frac{1}{2} & for \quad protons. \end{cases}$$

It is clear that the isovector and Coulomb terms voilate the isospin symmetry of the potential in Eq. (10),

$$\left[\hat{H}_{sp} - V_C, \hat{T}_\mu\right] \neq 0 . \tag{12}$$

Here, in the second quantisation representation single-particle Hamiltonian is

$$\hat{H}_{sp} = \sum_{\tau,j,m} \varepsilon_{jm}(\tau) a^{+}_{jm}(\tau) a_{jm}(\tau) \qquad (\tau = n, p) . \tag{13}$$

Where $\varepsilon_{jm}(\tau)$ is single-particle energy of nucleons with angular momentum j, and $a^{+}_{jm}(\tau), a_{jm}(\tau)$ is single particle creation (annihilation) operator.

Isospin operators, $\hat{T}_\mu$ are defined as,

$$\hat{T}_\mu = \begin{cases} \hat{T}_z & \mu = 0 \\ (\hat{T}_x + i\mu\hat{T}_y) & \mu = \pm 1. \end{cases} \tag{14}$$

Additionally,

$$T_- = \sum_{i=1}^{A} t_-^i \qquad , \qquad T_+ = \sum_{i=1}^{A} t_+^i \ .$$

Eq. (12) explains that there is a residual interaction, which breaks the isospin symmetry because of the isovector term in the shell model Hamiltonian. The breaking effect of this interaction should be eliminated using a method and Pyatov's restoration method is used for the situation [23, 24]. According to the related method, the breaking symmetry of the model Hamiltonian is restored by adding a proper residual force to the Hamiltonian. Residual interaction $\hat{h}$ should satisfy following condition:

$$\left[\hat{H}_{sp} - V_c(r) + \hat{h}, \hat{T}_\mu\right] = 0 \ . \tag{15}$$

Pyatov showed that $\hat{h}$ has to be form given as,

$$\hat{h} = \frac{1}{2\gamma}\left[\hat{H}_{sp} - V_c(r), \hat{T}_\mu\right]^+ \left[\hat{H}_{sp} - V_c(r), \hat{T}_\mu\right]. \tag{16}$$

The γ is an average of double commutator in the ground state,

$$\gamma \equiv C = \left\langle 0 \left| \left[\left[\hat{H}_{sp} - V_C, \hat{T}_{-\mu}\right], \hat{T}_\mu\right] 0 \right\rangle . \tag{17}$$

Such a form of the residual interaction allows us to simply treat the Coulomb mixing effects of the isospin. Thus, restoration of isotopic invariance for nuclear part of the Hamiltonian is satisfied and, the total Hamiltonian operator can be written in the form as,

$$\hat{H} = \hat{H}_{sp} + \hat{h} \ . \tag{18}$$

The Fermi transition matrix elements between the isobaric 0^+ states of neighbor nuclei are defined as;

a) for the transitions (N,Z) → (N-1,Z+1);

$$M^i_{\beta^-} = \left\langle 0 \left\| \left[\hat{Q}_i, \hat{T}_-\right] 0 \right\rangle = \sum_j \psi_j(p,n) \left\langle j,p \right\| j,n \right\rangle \left(N_j(n) - N_j(p)\right), \tag{19}$$

b) for the transitions (N, Z) → (N+1, Z-1);

$$M^i_{\beta^+} = \left\langle 0 \left\| \left[\hat{Q}_i, \hat{T}_+\right] 0 \right\rangle = -\sum_j \psi_j(p,n) \left\langle j,p \right\| j,n \right\rangle \left(N_j(n) - N_j(p)\right). \tag{20}$$

It is possible to show that the transitions in question obey the Fermi's sum rule,

$$\sum_i \left\{ \left| M^i_{\beta^-} \right|^2 - \left| M^i_{\beta^+} \right|^2 \right\} = \sum_j \left| \langle j, p \| j, n \rangle \right|^2 \left(N_j(n) - N_j(p) \right) = 2T_0 = N - Z \,. \qquad (21)$$

Here, $N_j(n)$ and $N_j(p)$ are occupation numbers of the corresponding neutron and proton states, respectively. The related method is expressed in Ref. [23-26], is detail.

3. CALCULATIONS AND RESULTS

In this section, behaviour of Ft values of the superallowed transitions are performed by considering the pairing correlations between nucleons and, including the effective interaction term in a self-consistent way. Without pairing and with pairing interaction values have been calculated within the framework of RPA and QRPA, respectively.

In the calculations, the Woods-Saxon potential with the Chepurnov parameterization [37] was used and the pairing correlation function was chosen as $C_n = C_p \approx 12/\sqrt{A}$ for the open shell nuclei.

In Table 1, the first column represents the superallowed Fermi beta transitions parent nucleus. The values for ft, $\delta'_R(\%)$, $\delta_{NS}(\%)$, $\delta_{C2}(\%)$ and $\Delta^v_R = (2.361 \mp 0.038)\%$ are adopted from Ref.[38]. In the fifth and sixth columns, the isospin symmetry breaking correction term $\delta_{C1}(\%)$ calculations based on the Pyatov method have been tabulated without and with pairing interactions, respectively. It is not possible to calculate the pairing effect of the ^{10}C and ^{14}O because of the poor nucleon number so results are same for these nuclei both without and with pairing results. In the eighth and nineth columns, the Ft values calculated from Eq. (7) have been given. The $\delta_{C1}(\%)$ and Ft values have been taken from our previous works [34, 35].

Table 1. Ft values of the eleven superallowed beta transitions.

Parent Nucleus	ft (sec)	δ_R'(%)	δ_{NS}(%)	δ_{C1}(%) [34]	δ_{C1}(%) [35]	δ_{C2}(%)	Ft (sec) [34]	Ft (sec) [35]
^{10}C	3039.5(47)	1.679(4)	-0.345(35)	1.399	1.399	0.165(15)	3103.0(51)	3103.0(51)
^{14}O	3042.5(27)	1.543(8)	-0.245(50)	0.578	0.578	0.275(15)	3127.7(34)	3127.7(34)
^{26m}Al	3037.0(11)	1.478(20)	0.005(20)	0.168	0.410	0.280(15)	3140.7(19)	3133.0(19)
^{34}Cl	3050.0(11)	1.443(32)	-0.085(15)	0.017	0.510	0.550(45)	3146.4(24)	3130.8(24)
^{38m}K	3051.1(10)	1.440(39)	-0.100(15)	-0.150	0.750	0.550(55)	3152.3(27)	3123.8(27)
^{42}Sc	3046.4(14)	1.453(47)	0.035(20)	-0.142	0.755	0.645(55)	3148.8(30)	3120.5(30)
^{46}V	3049.6(16)	1.445(54)	-0.035(10)	-0.219	1.070	0.545(55)	3155.3(32)	3114.5(31)
^{50}Mn	3044.4(12)	1.445(62)	-0.040(10)	-0.449	1.370	0.610(50)	3155.0(30)	3097.5(30)
^{54}Co	3047.6(15)	1.443(71)	-0.035(10)	-0.245	2.110	0.720(60)	3148.4(35)	3073.9(35)
^{62}Ga	3075.5(14)	1.459(87)	-0.045(20)	0.716	5.570	1.20(20)	3131.4(72)	2976.4(71)
^{74}Rb	3084.3(80)	1.50(12)	-0.075(30)	0.516	7.250	1.50(25)	3137.5(132)	2921.7(128)

The conserved vector current (CVC) hypothesis indicates that the Ft values should be constant for the superallowed Fermi beta decays. The studies in literature have been conducted in this respect, except for Wilkinson. Wilkinson suggested that the variation of Ft values according to Z should be quadratically after performing the isospin breaking correction [9, 13]. A lot of his works on this subject are available [9, 13, 18-22]. The Ft values for Z=0 has been found to extrapole quadratic variable. Thus, all effects depending on the charge have been removed to the calculations. However, Wilkinson did not use the δ_C values obtained for each nucleus for this quadratic behaviour [13]. Firstly the average value and, secondly the fluctuation value have been used for the isospin symmetry breaking correction.

The Ft values of both without and with pairing interactions versus Z have been seen in Figure 1 and 2, respectively. As seen in Figures, the behavior of $Ft - Z$ changing is quadratic as Wilkinson's. As a result of the graphics extrapolation to Z=0, from Figure 1, the Ft value of without pairing is 3080.17 sec. while the data with pairing from Figure 2 is 3048.31 sec. As can be seen in Table 1 and Figures, the Ft values with pairing are smaller than without pairing values.

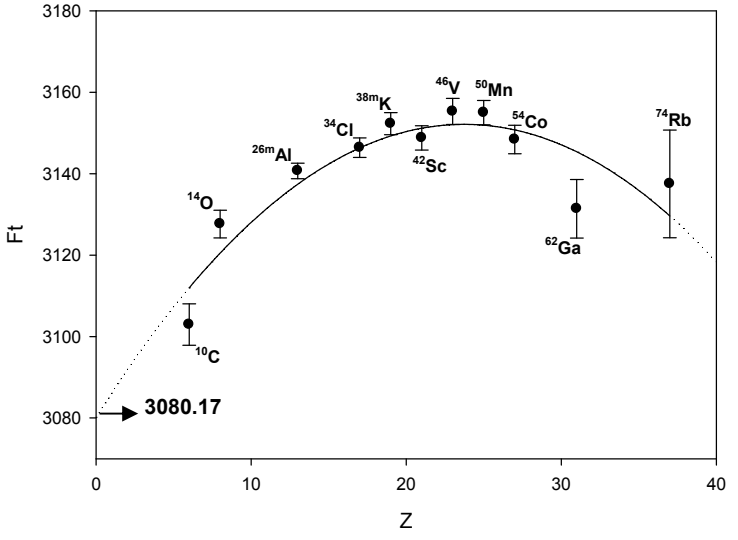

Figure 1. Calculated *Ft* values versus Z (without pairing).

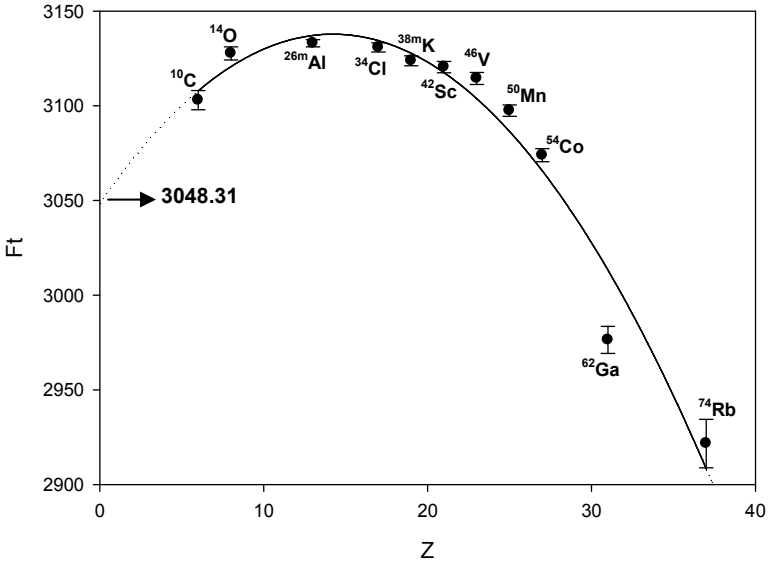

Figure 2. Calculated *Ft* values versus Z (with pairing).

This result can be explained as; when the pairing is considered density of final states of the transition are increasing and, due to the strength of the transition re-distribution between these new states the Ft values are decrease.

From the Eq. (9), V_{ud}^2 values have been found for without and with pairing calculations as 0.9689(8) and 0.9790(8), in turn. In Table 2, the first column represents the calculated V_{ud} values found in the present study. V_{us} and V_{ub} values, which are the other elements of first row of CKM matrix and, taken from Ref. [39] have been given in second and third columns. The obtained unitarity has been tabulated in the last column. In both cases the unitarity of CKM matrix is the order of one. In without pairing calculations, the deviation from the unity is % 1.171 and, taking into account of pairing between nucleons the deviation is about % 2.72. The present results are essentially in good agrement with the literature.

Table2. The unitarity ($V_{ud}^2 + V_{us}^2 + V_{ub}^2$) of the CKM matrix.

(V_{ud}) Present Work	(V_{us}) [39]	(V_{ub}) [39]	Obtained Unitarity ($V_{ud}^2 + V_{us}^2 + V_{ub}^2$)
0.9843(4) (without pairing)	0.2196(23)	0.0036(10)	1.0171(13)
0.9894(4) (with pairing)			1.0272(13)

4. CONCLUSION

In the present study, the Ft values of the superalloved $0^+ \to 0^+$ Fermi beta transitions changing according to Z have been found quadratically as Wilkinson's. In the calculations the broken isotopic symmetry of the Hamiltonian has been restored by Pyatov method. Wilkinson did not use the δ_C values obtained for each nucleus for the quadratic behaviour. If Wilkinson used his own calculated results for the isospin breaking correction each nucleus, the $Ft - Z$ changing would not be obtained as quadratic. In the present work, the obtained δ_C values has been used for each nucleus. This situation increases reliability of the method used here.

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REFERENCES

[1] Blin-Stoyle R J., "Isospin In Nuclear Physics", edited by Wilkinson D H., Amsterdam: North-Holland, 115-172 (1969).

[2] I.S. Towner and J.C. Hardy, "Superallowed 0^+->0^+ nuclear β-decays", Nucl. Phys. A, 205, 33 (1973).

[3] D.H. Wilkinson, "The mismatch problem in super-allowed Fermi β-decay", Phys. Lett., 65 B, 9 (1976).

[4] J.C. Hardy and I.S. Towner, "Superallowed 0^+->0^+ nuclear β-decays and Cabibbo universality", Nucl. Phys. A, 254, 221 (1975).

[5] I.S. Towner, J.C. Hardy, and M. Harvey, "Analogue symmetry breaking in superallowed fermi β-decay", Nucl. Phys. A, 284, 269 (1977).

[6] W.E. Ormand and B.A. Brown, "Corrections to the Fermi Matrix Element for Superallowed β Decay", Phys. Rev. Lett., 62, 866 (1989).

[7] F.C. Barker, "On the nuclear-mismatch correction for superallowed 0^+->0^+ beta decays", Nucl. Phys. A, 537, 134 (1992).

[8] F.C. Barker, "Calculated values of the nuclear-mismatch correction for superallowed 0^+->0^+ beta decays", Nucl. Phys. A, 579, 62 (1994).

[9] D.H. Wilkinson, "Methodology for superallowed Fermi beta-decay Part III", Nucl. Instr. and Meth. A, 335, 201 (1993).

[10] W.E. Ormand and B.A. Brown, "Isospin-mixing corrections for *fp*-shell Fermi transitions", Phys. Rev. C, 52, 2455 (1995).

[11] H. Sagawa, N. Van Giai, and T. Suzuki, "Effect of isospin mixing on superallowed Fermi β decay", Phys. Rev. C, 53, 2163 (1996).

[12] P. Navrátil, B.R. Barrett, and W.E. Ormand, "Large-basis shell-model calculation of the $^{10}C \rightarrow ^{10}B$ Fermi matrix element", Phys. Rev. C, 56, 2542 (1997).

[13] D.H. Wilkinson, "Super-allowed Fermi beta-decay revisited", Nucl. Instr. and Meth. A, 488, 654 (2002).

[14] I.S. Towner and J.C. Hardy, "Calculated corrections to superallowed Fermi β decay: New evaluation of the nuclear-structure-dependent terms", Phys. Rev. C, 66, 035501 (2002).

[15] N. Cabibbo, "Unitary Symmetry and Leptonic Decays", Phys. Rev. Lett., 10, 531 (1963).

[16] M. Kobayashi and T. Maskawa, "CP-Violation in the Renormalizable Theory of Weak Interaction", Prog. Theor. Phys., 49, 652 (1973).

[17] J. C. Hardy and I. S. Towner, "Superallowed 0+→0+ nuclear β decays: A critical survey with tests of the conserved vector current hypothesis and the standard model", Phys. Rev. C, 71, 055501 (2005).

[18] D.H. Wilkinson, "Evaluation of G_V and G_A; CKM unitarity", Nucl. Instr. and Meth. A, 495, 65 (2002).

[19] D.H. Wilkinson, "Super-allowed Fermi beta-decay: CKM unitarity", J. Phys. G, 29, 189 (2003).

[20] D.H. Wilkinson, "Super-allowed Fermi beta-decay: a further visit", Nucl. Instr. and Meth. A, 526, 386 (2004).

[21] D.H. Wilkinson, "Super-allowed Fermi beta-decay", Nucl. Instr. and Meth. A, 543, 497 (2005).

[22] D.H. Wilkinson, "Super-allowed Fermi beta-decay: Unitarity of the CKM matrix", Nucl. Instr. and Meth. A, 555, 457 (2005).

[23] N. I. Pyatov and D. I. Salamov, "Conservation laws and collective exciations in nuclei", Nukleonika, 22, 127 (1977).

[24] N. I. Pyatov et al, "Self-consistent theory of Coulomb isospin mixing in nuclei", Sov. J. Nucl. Phys., 29, 10 (1979).

[25] T. Babacan et al, "The effect of the pairing interaction on the energies of isobar analogue resonances in $^{112-124}$Sb and isospin admixture in $^{100-124}$Sn isotopes", J. Phys. G, 30, 759 (2004).

[26] A. Küçükbursa, D. I. Salamov, T. Babacan and H.A. Aygör, "An investigation of the influence of the pairing correlations on the properties of the isobar analog resonances in A=208 nuclei", Pramana, 63, 947 (2004).

[27] T. Babacan, D. I. Salamov, and A. Küçük bursa, "Gamow-Teller 1^+ states ^{208}Bi.", Phys. Rev. C, 71, 037303 (2005).

[28] D. I. Salamov et al, "The isospin admixture of the ground state and the properties of the isobar resonances in medium and heavy nuclei", Pramana, 66, 1105 (2006).

[29] D. I. Salamov, S. Ünlü, and N. Çakmak, "Beta-transition properties for neutron-rich Sn and Te isotopes by Pyatov method", Pramana, 69, 369 (2007).

[30] T. Babacan, D. I. Salamov, and A. Küçük bursa, "Self-consistent calculations of isospin admixtures in the ground states of the N=Z nuclei in the mass region of 50–100" Nucl. Phys. A, 788, 279 (2007).

[31] N. Çakmak, S. Ünlü, and C. Selam, "Low-lying Gamow-Teller transitions in spherical nuclei", Phys. Atom. Nucl., 75, 8 (2012) [Yad. Fiz., 75, 10 (2012)].

[32] N. Çakmak, S. Ünlü, and C. Selam, "Gamow-Teller 1+ states in 112-124Sb isotopes", Pramana, 75, 649 (2010).

[33] N. Çakmak, S. Ünlü, K. Manisa and C. Selam, "The investigation of 0+<--> 0– beta decay in some spherical nuclei", Pramana, 74, 541 (2010).

[34] A. E. Çalık, M. Gerçeklioğlu, and D. I. Salamov, "Superallowed Fermi beta decay and the unitarity of the Cabibbo-Kobayashi-Maskawa Matrix", Z. Naturforsch., 64 a, 865 (2009).

[35] A. E. Çalık, M. Gerçeklioğlu, and C. Selam, "The ınfluence of paırıng correlatıons on the ısospın symmetry breakıng correctıons of superallowed fermı beta decays", Phys. Atom. Nucl., 76, (2013) [Yad. Fiz., 76, (2013)]. DOI: 10.7868/S004400271304003X

[36] A. E. Çalık, M. Gerçeklioğlu, and D. I. Salamov, "The isospin mixing and the superallowe Fermi beta decay", Pramana, 79, 417 (2012).

[37] V. G. Soloviev, "Theory of Complex Nuclei", New York: Pergamon, (1976).

[38] I.S. Towner and J.C. Hardy, "Improved calculation of the isospin-symmetry-breaking corrections to superallowed Fermi β decay", Phys. Rev. C, 77, 025501 (2008).

[39] I.S. Towner and J.C. Hardy, "The evaluation of Vud, experiment and theory", J. Phys.G, 29, 197 (2003).