$1f_{7/2}\,1d_{3/2}$ MODEL SPACE AND INELASTIC LONGITUDINAL C6 ELECTRON SCATTERING FORM FACTORS IN Ti-50, (RESIDUAL INTERACTION CONSIDERATION)

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Abstract

Skakura Arima Sebe "SAS" has been adopted as an effective interaction to generate the model space $1f_{7/2}\,1d_{3/2}$ wave functions with Harmonic oscillator wave functions (H.O) as a single particle wave function to study inelastic longitudinal C6 electron scattering form factors in Ti-50. The modern realistic M3Y effective nucleon- nucleon interaction with two sets of fitting parameters (Ried fitting (M3Y-P1), and Paris fitting (M3Y-P0)) is used. The adjustable interaction "MSDI" has been used as a residual interactions in the calculation of core polarization effects within the framework of first order perturbation theory with $2\hbar\omega$ excitation energy coupling the core orbits to the higher configurations one across the model space at normal transition. Theoretical results have been compared with the experimental data.
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Key words:F7 MB2, C6,Form Factors, 50Ti,M3Y.

الاغلفه الثانويه $1f_{7/2}\,1d_{3/2}$ كأنموذج فضاء و دراسه عوامل التشكل للاستطاره الالكترونيه الطوليه غير المرنه متعدده الاقطاب C6 لنواة Ti-50 (أعتبارات تفاعل البقيه)

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الخلاصة

أعتماد التفاعل المؤثر من نوع SAS كتفاعل مؤثر لأنموذج الفضاء $1f_{7/2}\,1d_{3/2}$ لتوليد الدوال الموجيه الخاصه بأنموذج الفضاء المذكور مع أعتماد دوال المتذبذب التوافقي كداله للجسيم المنفرد. تم أستخدام التفاعل الواقعي المؤثر بين النيوكليونين من الفصيله M3Y و بواقع مجموعتين من عوامل الضبط الاولى من نوع Paris و الاخرى من نوع Ried بالاضافه الى أستخدام التفاعل المضبط MSDI ، كتفاعل متبقي في حسابات تأثيرات أستقطاب القلب كتصحيح من المرتبه الاولى لدراسه عوامل التشكل للاستطاره الالكترونيه غير المرنه و المتعدده الاقطاب C6 في نواة Ti-50 و بطاقه تهيج مقدارها $2\hbar\omega$ و التي تربط أغلفه القلب الخامل مع التشكيلات العليا عبر انموذج الفضاء. تمت مقارنه النتائج النظريه مع المعطيات العمليه

Introduction

With electron scattering, one can immediately relate the cross section to the transition matrix elements of the local charge and current density operators and thus directly to the structure of the target itself. Of course, the same considerations apply to processes involving real photons, but electrons have the second great advantage that for a fixed energy loss of the electron, one can vary the three-momentum transferred (q) to the nucleus, the only restriction being that the four momentum transfer be space-like [1].

Theoretical solutions to the nuclear many-body problem are partly phenomenological, and thus theory and experiment are closely tied together. Theory takes its inspiration from experiment in guiding the structure of the models and their parameters; the nuclear shell model is the primary example. Nuclear experiment takes its inspiration from theory in helping to choose which experiments are most important to prove or disprove model assumptions [2].

Through microscopic theory, the discarded space are include as a first order perturbation through particle hole state (p-h), and using mixing interaction in order to calculate these effects as a residual interaction, some of the most widely mixing interaction used to calculate this effect are (modifed-surface delta function interaction (MSDI)[3], Michigan sum of three-range Yukawa potential (M3Y)[4], Skyrme-type hamiltonian (SKX)[5], Skyrme-type hamiltonian (MSK7)[6],Dirac-Hartree hamiltonian (NL3)[7], Gogny interactions D1S[8] and the process is called Core polarization (C P).

Differential cross sections for inelastic electron scattering from ^{50}Ti had been measured and fitted using two representations for the transition charge, (i) the hydrodynamic liquid drop, and (ii) a phenomenological model. [9] the cross sections for the strongly excited, 2^+, 3^-, 4^+ and 5^- levels had been measured over a range of momentum transfer (q) of 0.4−2.6 fm^{-1} Experimental $|F(q)|^2$ for the C6 transitions in ^{50}Ti over a range of momentum transfer (q) of 0.4−2.6 fm^{-1} had been measured [10].

The inelastic Coulomb form factor for electroexcitation of the yrast 6^+ state in ^{50}Ti had been measured [11]. The value for the root mean square charge radius of the 1f$_{7/2}$proton orbit deduced from these data is appreciably larger than the one extracted from the M7 form factor for elastic magnetic scattering from ^{51}V .

Inelastic electron scattering from fp shell Nuclei had been studied [12]. The calculated form factors for ^{50}Ti had been performed by the use of Hartree Fock theory, results are in a good agreement with the experimental data.

Shell-model and core-polarization calculations for the yrast, $J^\pi = 2^+$, 4^+ and 6^+ levels in ^{50}Ti , Charge form factors had been deduced and compared with experimental data [13], emphasizing the radial shape of the model wave function in comparison with the *q*-dependence of the data. The radial effect is explained in detail by configuration mixing and core-polarization calculations.

In ^{50}Ti , (1f$_{7/2}$) neutron orbit radius had been measured by the use of elastic electron scattering experiment and the result was r = 3.96 ± 0.05 [14].

In the framework of the Hartree-Fock model, the form factors for the inelastic electron scattering to 2^+, 4^+ and 6^+ states in $^{46,48,50}Ti$, $^{50,52,54}Cr$ and $^{54,56}Fe$ were studied [15, 16]. The calculation is performed in the 1f$_{7/2}$, 2 p$_{3/2}$, 1f$_{5/2}$, 2 p$_{1/2}$ model space using a modified Kuo-Brown effective interaction.

Inelastic longitudinal C6 electron scattering form factors had studied for ^{50}Ti for the excitation of 6^+ [17], by the use of shell model wave functions in 1f$_{7/2}$ and 1f$_{7/2}$ 1d$_{3/2}$ model spaces with the inclusion of core polarization in the calculation of the form factor with M3Y-E fitting [18] as a residual interaction, the core polarization contributions are in positive sign with respect to model space parts for all the three cases.

A computer program written in FORTRAN 90 language code by Prof. Radhi , which calculates the model space form factors zeroth-order and the first-order CP effects have been utilized. This computer program has been modified to receive the new set of fitting parameters belong to Paris and Ried fitting sets [21] .

Theory

For a selected operator T_{JT}^η the reduced matrix elements are written as the sum of the product of the one-body transition density matrix elements (OBDM) times the single-particle transition matrix elements [3]:

$$\left\langle \Gamma_f \middle\| \hat{T}_\Lambda^\eta \middle\| \Gamma_i \right\rangle = \sum_{\alpha,\beta} OBDM\left(\Gamma_i,\Gamma_f,\alpha,\beta\right)\left\langle \alpha \middle\| \hat{T}_\Lambda^\eta \middle\| \beta \right\rangle \quad (1)$$

where $\Lambda = JT$ is the multipolarity and the states $\Gamma_i \equiv J_i T_i$ and $\Gamma_f \equiv J_f T_f$ are initial and final states of the nucleus. While α and β denote the final and initial single-particle states, respectively (isospin is included).

The OBDM used in the present work are calculated by generating the wave functions of a given transition in the known nuclei from the modified version of the shell model code (OXBASH v.2005)[22] which contains a complete library of shell model effective interaction. All the informations about transitions of given multipolarities are contained in the OBDM which represents the combination of the model space wave functions.

The reduced matrix elements of the electron scattering operator $\hat{T}_\Lambda^\eta$ consist of two parts, one is for the "Model space" matrix elements, and the other is for the "Core-polarization" matrix elements are given by [23],

$$\left\langle \Gamma_f \middle\| \hat{T}_\Lambda^\eta \middle\| \Gamma_i \right\rangle = \left\langle \Gamma_f \middle\| \hat{T}_\Lambda^\eta \middle\| \Gamma_i \right\rangle_{MS} + \left\langle \Gamma_f \middle\| \delta \hat{T}_\Lambda^\eta \middle\| \Gamma_i \right\rangle_{CP} \quad (2)$$

Where, $\left\langle \Gamma_f \middle\| \hat{T}_\Lambda^\eta \middle\| \Gamma_i \right\rangle_{MS}$ are the model-space matrix elements,

and, $\left\langle \Gamma_f \middle\| \delta T_\Lambda^\eta \middle\| \Gamma_i \right\rangle_{CP}$ are the core-polarization matrix elements.

$|\Gamma_i\rangle$ and $|\Gamma_f\rangle$ are described by the model-space wave functions.

The core-polarization matrix elements in equation (2) can be written as [23]:

$$\left\langle \Gamma_f \middle\| \delta \hat{T}_\Lambda^\eta \middle\| \Gamma_i \right\rangle_{cp} = \sum_{\alpha,\beta} OBDM(\alpha,\beta)\left\langle \alpha \middle\| \delta \hat{T}_\Lambda^\eta \middle\| \beta \right\rangle_{cp} \quad (3)$$

The first order perturbation theory says that the single-particle matrix element for the higher-energy configurations can be expressed as [3]:

$$\left\langle \alpha \middle| \delta \hat{T}_J^\eta \middle| \beta \right\rangle = \left\langle \alpha \middle| V_{res} \frac{Q}{E-H^{(0)}} \hat{T}_J^\eta \middle| \beta \right\rangle + \left\langle \alpha \middle| \hat{T}_J^\eta \frac{Q}{E-H^{(0)}} V_{res} \middle| \beta \right\rangle \quad (4)$$

The single-particle energies are calculated according to [3]:

$$e_{nlj} = (2n+l-\tfrac{1}{2})\hbar\omega + \begin{cases} -\tfrac{1}{2}(l+1)\langle f(r)\rangle_{nl} \; for \; j=l-\tfrac{1}{2} & (5) \\[2mm] \tfrac{1}{2}l\langle f(r)\rangle_{nl} \quad for \; j=l+\tfrac{1}{2} \end{cases}$$

with:

$$\langle f(r)\rangle_{nl} \approx -20A^{-2/3} MeV \quad (6)$$

$$\hbar\omega = 45A^{-1/3} - 25A^{-2/3}$$

For the two-body matrix elements of the residual interaction $\left\langle \alpha\alpha_2 \middle| V_{res} \middle| \beta\alpha_1 \right\rangle_\Gamma$, which appear in equation (4), the Michigan sum of three range Yukawa potential (M3Y) interaction of Berstch et. al [4] is adopted. This interaction containing terms like those were given in LS-coupling and tensor effects. A transformation of the wave function from jj to LS coupling must be done to get the relation between the two-body shell model matrix elements and the relative and centre of mass coordinates, using the harmonic oscillator radial wave functions with Talmi-Moshinsky transformation.

The realistic M3Y effective NN interaction, which is used in electron scattering ($V_{res} = V_{12}$) is expressed as a sum of the central potential part $v_{12}^{(C)}$, spin-orbit potential part $v_{12}^{(LS)}$, and long range tensor part $v_{12}^{(TN)}$, as follows [4],[21]:

$$V_{12}\,^{(M3Y-P0)} = v_{12}^{(c)} + v_{12}^{(LS)} + v_{12}^{(TN)}$$

$$V_{12}\,^{(M3Y-P1)} = v_{12}^{(c)} + v_{12}^{(LS)} + v_{12}^{(TN)} + v_{12}^{(DD)} \quad (7)$$

The four potentials are expressed as: [21]

$$v_{12}^{(c)} = \sum_n (t_n^{(SE)} P_{SE} + t_n^{TE} P_{TE} + t_n^{(SO)} P_{SO} + t_n^{(TO)} P_{TO}) f_n^{(C)}(r_{12})$$

$$v_{12}^{(LS)} = \sum_n (t_n^{(LSE)} P_{TE} + t_n^{(LSO)} P_{TO}) f_n^{(LS)}(r_{12}) L_{12}\cdot(\vec{s}_1 + \vec{s}_2) \quad (8)$$

$$v_{12}^{(TN)} = \sum_n (t_n^{(TNE)} P_{TE} + t_n^{(TNO)} P_{TO}) f_n^{(TN)}(r_{12}) r_{12}^2 S_{12}$$

$$v_{12}^{(DD)} = (t_{dd}^{SE} P_{SE} + t_{dd}^{TE} P_{TE}) \delta(r_{12})$$

The values of the best fit to the potential parameters

$(t_n^{(SE)}, t_n^{(SO)}, t_n^{(TO)}, t_n^{(TE)}, t_n^{(LSE)}, t_n^{(LSO)}, t_n^{(TNE)},$ $t_n^{(TNO)}, t_{dd}^{(SE)}, t_{dd}^{(TE)}$ are shown in Table -1 for M3Y-P1 and

$(t_n^{(SE)}, t_n^{(SO)}, t_n^{(TO)}, t_n^{(TE)}, t_n^{(LSE)}, t_n^{(LSO)}, t_n^{(TNE)},$ $t_n^{(TNO)}$ for M3Y-P0 in Table -2 [21].

Table-1:. The values of the best fit to the potential parameters belongs to Ried fitting (M3Y-P1) [21], for TN, R2 = 0.7 fm.

	R_1=0.25 fm	R_2=0.40 fm	R_3=1.414 fm
Oscillator matrix elements (Channel)	t_1	t_2	t_3
Central Singlet-Even (SE)	8599.5	-3556	-10.463
Central Triplet-Even (TE)	10475.25	-4594	-10.463
Central Singlet-Odd (SO)	-1418	950	31.389
Central Triplet-Odd (TO)	11345	-1900	3.488
Tensor-Even (TNE)	-131.52	-3.708	0.0
Tensor-Odd (TNO)	29.28	1.872	0.0
Spin-Orbit Even (LSE)	-9181.8	-606.6	0.0
Spin-Orbit Odd (LSO)	-3414.6	-1137.6	0.0
Density dependent Singlet-Even (SE) $t_{dd}^{(SE)}$ =1090			
Density dependent triplet-Even (TE) $t_{dd}^{(TE)}$ =1332			

Table-2: The values of the best fit to the potential parameters belong to Paris [21].

	R_1=0.25 fm	R_2=0.40 fm	R_3=1.414 fm
Oscillator matrix elements (Channel)	t_1	t_2	t_3
Centeral Singlet-Even (SE)	11466	-3556	-10.463
Central Triplet-Even (TE)	13967	-4594	-10.463
Central Singlet-Odd (SO)	-1418	950	31.389
Central Triplet-Odd (TO)	11345	-1900	3.488
Tensor-Even (TNE)	0.0	-171.7	-78.03
Tensor-Odd (TNO)	0.0	283.0	13.62
Spin-Orbit Even (LSE)	0.0	-813.0	0.0
Spin-Orbit Odd (LSO)	-2672	-620.0	0.0

MSDI as a residual interaction is the touchstone in this paper because this type of interactions (adjustable) will give us the general behavior of the core polarization part with respect to the model space one and expose the reasons behind the negative sign in the addition process (core polarization + model space) as we had seen and without a prolonged analysis the matrix element of this type of interaction might be expressed as follows [3],

$$\langle j_1 j_2 | V_{(1,2)}^{MSDI} | j_3 j_4 \rangle_{JT} = \frac{1}{2} A_T (-1)^{n_1-n_2+n_3+n_4}$$

$$\sqrt{\frac{(2j_1+1)(2j_2+1)(2j_3+1)(2j_4+1)}{(1+\delta_{12})(1+\delta_{34})}}$$

$$\left\{ (-1)^{j_2+j_2+l_4+l_2} \begin{pmatrix} j_1 & j_2 & J \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{pmatrix} \begin{pmatrix} j_3 & j_4 & J \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{pmatrix} [1-(-1)^{l_3+l_4+J+T}] \right.$$

$$\left. - \begin{pmatrix} j_1 & j_2 & J \\ \frac{1}{2} & \frac{1}{2} & -1 \end{pmatrix} \begin{pmatrix} j_3 & j_4 & J \\ \frac{1}{2} & \frac{1}{2} & -1 \end{pmatrix} [1+(-1)^T] \right\}$$

$$+[(2T(T+1)-3)B+C]\delta_{12}\delta_{34} \qquad (9)$$

where,

$A0= A1= B =25/A, C \approx 0$ [3]

Results and Discussion

The core-polarization effects has been included in order to account for the contribution of configurations from outside of the model space in the transition.

The model space adopted in the present work is $1f_{7/2}$ $1d_{3/2}$ subshell orbits as a model space for ^{50}Ti. Core-polarization effects are taken into account through first order perturbation theory, which allows particle-hole excitation from shell core orbits $1s_{3/2}$, $1p_{3/2}$, $1p_{1/2}$, $1d_{5/2}$, $1d_{3/2}$ and $2s_{1/2}$ (shell model space having ^{40}Ca as an inert core) and $1s_{1/2}$, $1p_{3/2}$, $1p_{1/2}$, $1d_{5/2}$ and $2s_{1/2}$ (shell model space having ^{32}S as an inert core) to all higher orbits with $2\hbar\omega$ excitation for normal transitions.

Sakakura, Arima and Sebe (SAS) interaction is adopted [27] as the effective interaction in this paper for the model space $(1f_{7/2}$ $Id3/2$ $)$ shell model wave functions for ^{50}Ti.

The CP effects are calculated with the realistic effective interactions M3Y-P1 and M3Y-P0 [21] and MSDI [3] as a residual interaction. In this interaction, the Ried and Paris fitting have been used to calculate the radial integral.

Electron scattering C6 form factor in ^{50}Ti $(1f_{7/2}$ $1d_{3/2})$ model space with SAS [27] as a model space effective interaction

The nucleus ^{50}Ti is really $\{^{32}S$ +18 protons and neutrons distributed in subshell $1f_{7/2}$ $1d_{3/2}$ the space that be choosen to study the behavior of this system under excitation by the use of electron scattering and calculating multipole form factor. ^{32}S as an inert core and the model space effective interaction SAS [27] has been adopted to generate the model space wave functions, and Table-3 shows the values of OBDM for the C6 form factors for the model space $(1f_{7/2}$ $)$ and   SAS **as** a model space effective interaction calculation in ^{50}Ti.

Figure-1 shows the C6 form factor calculated with the use of M3Y-P0 as a residual interaction and this results are consistent with the experimental one and it is clear that the model space form factor is underestimated the experimental one and the results show that the core polarization has minor contribution and in opposite sign with respect to model space so that the total C6 form factors are quenched.

Protons in model space will be dominantly responsible to this coulomb form factor (e_p=1e).

Return to the figure-1, it is clear that the core contribution, model space and total form factors are in phase. The experimental data are taken from ref. [28].

Figure-2 shows the **C6** form factor calculated with the use of MSDI as a residual interaction and this results are consistent with the experimental one and it is clear that the model space form factor is in a reasonable agreement with the experimental one and the results show that the core contribution is weak in some extent but has the property of constructive interference so that the total C6 form factors are enlarged and it is overestimated and they are (core contribution, model sp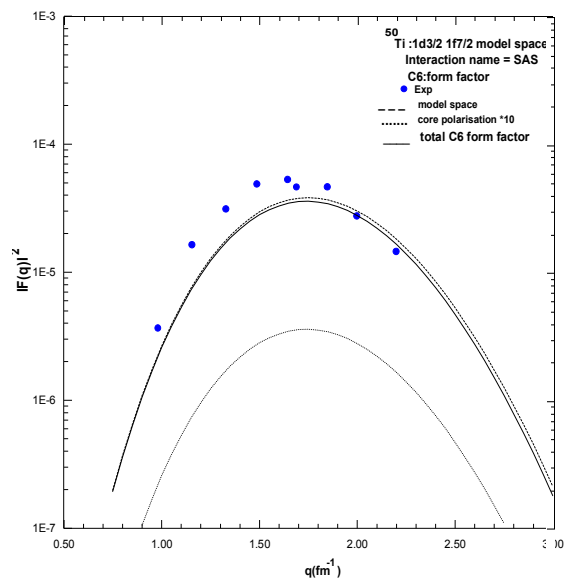ace   and total form factors) are in phase and figure.-3 shows the inelastic longitudinal C6 form factors in ^{50}Ti nucleus, for the $1f_{7/2}$ model space calculation, and SAS as a model space effective interaction, (M3Y-P1) as a residual interaction. The core polarization has a constructive and enhancement properties, excellent agreement have been obtained, experimental data are taken from ref [28].

Table- 4:The values of OBDM for the C6 form factors for the   model space ($1f_{7/2}$ $1d_{3/2}$) and SAS [27] as a model space effective interaction calculation in ^{50}Ti.

J_i	J_f	OBDM $(\Delta T=0)$	OBDM $(\Delta T=1)$
7/2	7/2	1.34361	-0.89574

Figure-1:Inelastic longitudinal C6 form factors in ^{50}Ti nucleus, for the $1f_{7/2}$ model space calculation, and SAS as a model space effective interaction at Ex=3.404 MeV (the value of Ex is theoretical), experimental data are taken from ref. [23], and M3Y-P0 as a residual interaction.
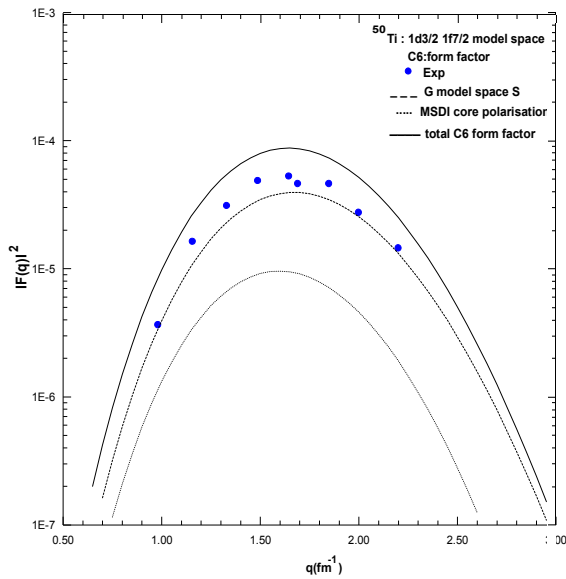
Figure-2:Inelastic longitudinal C6 form factors in ^{50}Ti nucleus, for the $1f_{7/2}$ model space calculation, and SAS as a model space effective interaction at Ex=3.404 MeV (the value of Ex is theoretical), experimental data are taken from ref [23], and MSDI as a residual interaction.
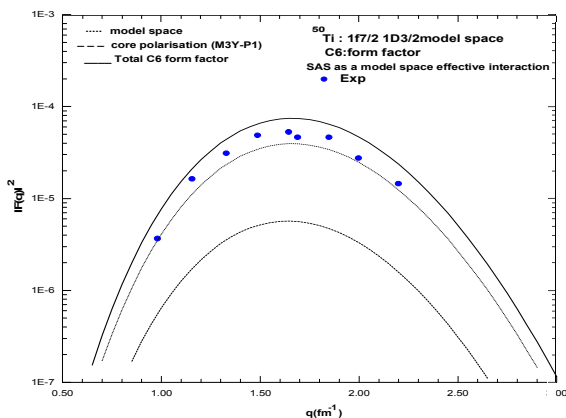

Figure.-3;Inelastic longitudinal C6 form factors in ^{50}Ti nucleus, for the $1f_{7/2}$ model space calculation, and SAS as a model space effective interaction at Ex=3.404 MeV (the value of Ex is theoretical), experimental data are taken from ref [23]. and (M3Y-P1) as a residual interaction.

Conclusions

1.In fp shell model space with many body problem, the model space contribution is found dominant with respect to the core one for the three cases.

2.Core polarization has a constructive contribution when we use (MSDI) and (M3Y-P1) as a residual interactions in comparison with M3Y-P0.

3.Use of two versions of M3Y with two different sets of fitting parameters do change the behavior of the core polarization contribution especially in amplitudes and phases where the

density dependence has the dominant contribution.

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