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Core-polarization effect in longitudinal electron scattering form factors of ^{65}Cu nucleus

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Abstract

Inelastic longitudinal electron scattering form factors to 2^+ and 4^+ states in ^{65}Cu nucleus has been calculated in the ($2p_{3/2}$ $1f_{5/2}$ $2p_{1/2}$) shell model space with the F5PVH effective interaction. The harmonic oscillator potential has been applied to calculate the wave functions of radial single-particle matrix elements. Two shell model codes, CP and NUSHELL are used to obtain results. The form factor of inelastic electron scattering to $1/2_1^-$, $1/2_2^-$, $3/2_2^-$, $3/2_3^-$, $5/2_1^-$, $5/2_2^-$ and $7/2^-$ states and finding the transition probabilities B (C2) (in units of $e^2\,fm^4$) for these transitions and B (C4) (in units of $e^2\,fm^8$) for the transition $7/2^-$, and comparing them with experimental data. Both the form factors and reduced transition probabilities with core-polarization effects gave a reasonable description of the experimental data.

Key words

Electron scattering, she
model, form factor, cor
polarization.

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تاثير استقطاب القلب في عوامل التشكل الطولية للاستطارة الالكترونية في نواة ^{65}Cu

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الخلاصة

عوامل التشكل الطولية للاستطارة الالكترونية الغير مرنة للحالات 2^+ و4^+ في نواة ^{65}Cu تم حسابها في فضاء نموذج القشرة ($2p_{3/2}$ $1f_{5/2}$ $2p_{1/2}$) مع التفاعل المؤثر F5PVH. تم تطبيق جهد المتذبذب التوافقي لحساب دالة الموجة لعناصر مصفوفة الجسيم المنفرد القطرية. تم استخدام برنامجي نموذج القشرة CP و NUSHELL للحصول على النتائج. تم حساب عوامل التشكل واحتمالية الانتقال ومقارنتها مع القيم العملية للحالات $1/2_1^-$ و$1/2_2^-$ و $3/2_2^-$ و $3/2_3^-$ و $5/2_1^-$ و $5/2_2^-$ و $7/2^-$. ان كلا من عوامل التشكل واحتمالية الانتقال بادخال تاثير استقطاب القلب اعطت نتائج تصف القيم العملية بشكل مقبول.

Introduction

The structure of the nucleus can be described in nuclear physics by calculating some of the basic amount such as nuclear size, different nuclear densities and the associated charge form factor. Among these properties the most important one is the nuclear charge density distribution, which gives us much circumstantial information on the internal structure of nuclei since they are directly related to the wave functions of proton, which are paramount keys for many calculations in nuclear physics [1]. One of the successful ways is electron scattering since it interacts via quantum electrodynamics, which is believed to be the most delicate physical theory being known [2]. On the other hand, for fixed energy loss to the target, one can differ the three-momentum transfer $\vec{q}$ and map out the Fourier transforms of the static and transition densities. With electron scattering it can immediately relate the cross section to the transition matrix elements of the local charge and current density operators and this directly relate to the structure of the target itself [3]. Another important aspect is that the scattering is only sensitive to charge and can only probe the distribution of protons in the nucleus from the simple, inelastic scattering used to probe the interior structure of protons and neutrons [4].

Calculations of form factors using the model space wave function alone are inadequate for reproducing the data of electron scattering. Inelastic electron scattering provides a powerful method for investigating nuclear structure [5].In inelastic scattering, the differential cross section is measured for electrons that have lost a certain quantity of energy to the target, excited nuclear states are reached or additional particles are produced.

T. Mizusaki et al. [6] have been studied largely deformed rotational bands of ^{56}Ni and ^{58}Cu by the Monte Carlo shell model with full *pf* plus $g_{9/2}$ shell model space. These highly collective deformed bands can be well reproduced with the simultaneous description of spherical states, but the twinning of these bands is still in question. V.M. Khvastunov [7] have been carried out multipole (E0, E1, E2, E3, E4) on the ^{64}Zn, ^{65}Cu and ^{124}Sn nuclei. This study compared with other experimental and theoretical results. K. D. Sviratch et al. [8] have been studied the ability to account for the development of isovector pairing correlations, and collective rotational motion in many-particle, nuclear systems of low-lying energy spectra of ^{58}Ni and ^{58}Cu. Also comparison of three modern realistic interactions GXPF1, CD-Bonn and CD-Bonn+3terms in a broad range of nuclei in the upper *fp*-shell nuclei have been performed. M. Avrigeanu and V. Avrigeanu [9] studied the reaction mechanisms have been involved in the deuterons interaction for ^{27}Al and ^{63,65}Cu nuclei, at energies range 3-60 MeV, starting with elastic scattering until the evaporation from fully equilibrated compound system. The calculations were with predictions of the TALYS code in the cross-section where the importance of appropriate consideration in this mechanism. V.V. Denyak et al. [10] have been measured the inelastic electron scattering from ^{63,65}Cu nuclei at excitation energies of up to 5MeV. The reduced probability and multipolarity transitions were acquired for twelve low-lying levels of the ^{63}Cu and the seventeen levels of the ^{65}Cu. E. Simeckova et al. [11] have been measured the activation cross sections for ^{63,65}Cu nuclei with (d,p), (d,2n), (d,3n) and (d,2p) reactions on the energy range 4-20 MeV, using the stacked-foil technique, then following the available elastic scattering data analysis. The measured cross sections overall are agreement with the detroun cross section calculations. This confirms the corrections of the nuclear mechanism account which leads to the present analysis of the elastic scattering and reaction data. P. Vingerhoets et al. [12] measured the ground quadrupole moments of $^{58-60}$Cu nuclei using collinear laser spectroscopy with bunched atomic beams. The measured nuclear moments have been compared to large-scale shell-model calculations with the GXPF1 and GXPF1A effective interactions. C. J. Chiara et al. [13] have been extended the decay schemes for ^{65,67}Cu nuclei in reactions between 430MeV ^{64}Ni beam and a thick ^{238}U target. Shell-model calculations, using JUN45 and jj44b effective interactions have been carried out in ^{65,67}Cu nuclei.

The results with jj44b was providing overall better agreement with the experimental data. P.C. Srivastava and I. Mehrotra [14] have been studied the yrast levels of Ni, Cu and Zn isotopes using $p_{3/2}$, $f_{5/2}$, $p_{1/2}$, and $g_{9/2}$ valance space with^{56}Ni nucleus as a closed core. The obtained results indicate that the inclusion of $\pi f_{7/2}$ and $\upsilon d_{5/2}$ orbital's in the model space was an important. The full effective two body matrix elements (ETBME) approach to the *fp* shell interaction has been feasible by the (the group matrix fitted to *fp* shell nuclei with density dependence parameters) GXPF1 interaction and has been applied to all *fp* shell nuclei (A= 47-65). G. Bocchi et al. [15] had been measured the lifetime of the $9/2^+$ for ^{65}Cu nucleus. The B(E3) value equal 8.82 (165) W.U. have been deduced and compared to theoretical predictions of a particle vibration coupling model. I. Boztosun et al. [16] have been investigated the decays of ^{63}Zn, ^{65}Zn, ^{69}Zn, and ^{67}Cu nuclei produced by photonuclear reactions. Decay of several zinc isotopes has been measured and fitted, as well as, the Gamma energy levels of the daughters of those decays were measured with good accuracy. All of the measurements were consistent with established data within error bars.

The aim of the present work is to adopt the F5PVH [17] interaction in the *f5p* model space to calculate the model space form factors (zero-order) and the first-order core-polarization (CP) effects. In this work, the contribution of CP and higher energy configuration for particle-hole excitations up to $6\hbar\omega$ must be considered through perturbative core-polarization to investigate the Coulomb form factors for ^{65}Cu nucleus. The nucleon-nucleon realistic interaction Michigan three-rang Yukawa (M3Y) potential of Bertsch et al. [18] and Modified surface delta interaction (MSDI) [19] is chosen as a residual two-body interactions. And also the core-polarization effects are taking into account through giving the proton and the neutron model space effect charge. The one body density matrix (OBDM) elements are calculated by using the shell model NUSHELL code for computer [20] with F5PVH effective interaction [17].

Theory

Inelastic form factors for a given multipolarityΔ and momentum transfer q is written as[21]:

$$\left|F_{\Delta}^{\eta}(q)\right|^2 = \frac{4\pi}{Z^2(2X_i+1)}\left|\left\langle X_f \left\| T_{\Delta}^{\eta}(q) \right\| X_i \right\rangle\right|^2 \left|F_{c.m}F_{f.s}\right|^2 \tag{1}$$

where $F_{c.m} = e^{\frac{q^2b^2}{4A}}$ is the center-of-mass correction [22], A is the mass number, b is the harmonic oscillator size parameter, Z is the atomic number, $\Delta \equiv JT, X_i \equiv J_iT_i$, $X_f \equiv J_fT_f$ and $F_{f.s} = \left[1+\left(q/4.33\,fm^{-1}\right)^2\right]^{-2}$ is the finite size correction [23]. The reduced matrix elements are given as the sum of the model space (MS) and CP effects [24]

$$\left\langle X_f \left\| \hat{T}_{\Delta}^{\eta} \right\| X_i \right\rangle = \left\langle X_f \left\| \hat{T}_{\Delta}^{\eta} \right\| X_i \right\rangle_{MS} + \left\langle X_f \left\| \delta\hat{T}_{\Delta}^{\eta} \right\| X_i \right\rangle_{CP} \tag{2}$$

where η represents the longitudinal (L), or transverse form factors (electric (E) and magnetic(M)). The model space (MS) matrix elements can be written as,

$$\left\langle X_f \left\| \hat{T}_{\Delta}^{\eta} \right\| X_i \right\rangle_{MS} = \sum_{\alpha,\beta} OBDM\left(X_i, X_f, \alpha, \beta\right)\left\langle \alpha \left\| \hat{T}_{\Delta}^{\eta} \right\| \beta \right\rangle \tag{3}$$

the OBDM is obtained from NUSHELL code [20], the core-polarization (CP) matrix elements are given as,

$$\left\langle X_f \left\| \delta\hat{T}_{\Delta}^{\eta} \right\| X_i \right\rangle_{CP} = \sum_{\alpha,\beta} OBDM\left(X_i, X_f, \alpha, \beta\right) \left\langle \alpha \left\| \delta\hat{T}_{\Delta}^{\eta} \right\| \beta \right\rangle \tag{4}$$

which determined by using CP code to calculate the form factors[25], In the shell- model theory, the true space may be divided into three separated spaces, which are: model space, closed inert core and higher configurations. Higher configurations may be included or excluded according to the choice of the researcher and the model that he uses. Shell model calculations, carried out within a model space in which the nucleons are bound to occupy few orbits are unable to reproduce the experimental data. In the context of the shell model the wave functions revealed by the need to take into account higher configurations. These higher configurations are called CP. The first order perturbation theory is used, and then the single-particle matrix element of the one body operator can be expressed as [19]:

$$\left\langle \alpha \left| \delta\hat{T}_J^{\eta} \right| \beta \right\rangle = \left\langle \alpha \left| V_{res} \frac{Q}{E-H^{(0)}} \hat{T}_J^{\eta} \right| \beta \right\rangle + \left\langle \alpha \left| \hat{T}_J^{\eta} \frac{Q}{E-H^{(0)}} V_{res} \right| \beta \right\rangle \tag{5}$$

where Q is the projection operator onto the space outside the model space, V_{res} is the residual interaction, which M3Y and MSDI interactions are used. The two terms on the right hand side of Eq.(5) can be written as [26]:

$$\begin{aligned}\left\langle \alpha \left| \hat{T}_J^{\eta} \frac{Q}{E-H^{(0)}} V_{res} \right| \beta \right\rangle = & \sum_{phX} \frac{(-1)^{\alpha_i+h+X}}{e_{\alpha_i} - e_{\alpha_f} - e_p + e_h} (2X+1) \begin{Bmatrix} \alpha_f & \alpha_i & \Delta \\ h & p & X \end{Bmatrix} \sqrt{(1+\delta_{p\alpha_f})(1+\delta_{h\alpha_i})} \left\langle h \left\| T_{\Delta} \right\| p \right\rangle \\ & \times \left\langle \alpha_f\, p \left| V_{res} \right| \alpha_i h \right\rangle_{\mathrm{X}} \\ & + Terms \quad \text{with } p \text{ and } h \text{ exchanged with an overall minus sign,}\end{aligned} \tag{6}$$

where p runs over particle states and h over hole states and e is the single-particle energy which is calculated according to [27]:

$$e_{nlj} = (2n+l-\frac{1}{2})\hbar\omega + \begin{cases} -\frac{1}{2}(l+1)\left\langle f(r) \right\rangle_{nl} & for \quad j = l - \frac{1}{2} \\ \frac{1}{2} l \left\langle f(r) \right\rangle_{nl} & for \quad j = l + \frac{1}{2} \end{cases} \tag{7}$$

with $\left\langle f(r) \right\rangle_{nl} \approx -20A^{-2/3}$ and $\hbar\omega = 45A^{-1/3} - 25A^{-2/3}$ the electric transition strength is given by,

$$B(C\Delta, k) = \frac{Z^2}{4\pi}\left[\frac{(2\Delta+1)!!}{k^{\Delta}}\right]^2 F_{\Delta}{}^2(K) \tag{8}$$

where k = E_X /ħc

Results and discussion

The ^{65}Cu nucleus (odd-A nucleus) has 9 nucleons (8 neutrons and one proton) outside the closed core ^{56}Ni nucleus, the ground state of its ($J^{\pi}T=3/2^{-}$ 7/2). So far, the study of odd-A nuclei by inelastic electron scattering is less complete and systematized than that of even-even nuclei. This is due to the fact that in odd-A nuclei several multipolarties may contribute in each transition [28]. For the present investigation the ^{65}Cu nucleus, it is possible to carry out shell-model calculations for this nucleus in *f5p* shell model space. The effects of higher configurations outside the *fp*-shell model space, which are called CP effects are taken into account through a microscopic theory (allows particle-hole excitations up to $6\hbar\omega$) to calculate the C2 and C4 form factors. The radial wave functions of the single-particle matrix elements have been calculated with the harmonic oscillator (HO) potential for considering transitions with size parameter b_{rms} =1. 90*fm* was chosen to reproduce the measured root mean square charge radii [29].

A comparison between the experimental and theoretical form factors for C2 and C4 transitions for ^{65}Cu nucleus are shown by the figures below. The CP effect is calculated with the MSDI and M3Y as residual two body interactions by CP code [25]. The strength of MSDI is denoted by A_T, B and C were chosen without any adjusted parameter. These parameters are taken to be $A_0= 0.5$, $A_1=0.3$, $B=0.4$ and $C=0.07$ *MeV* [30], with respect M3Y interaction the parameters without any modified were chosen [18]. The OBDM elements obtained from NUSHELL [20] code using the F5PVH interaction [17]. In all figures the solid circles represent the experimental data, the plus line corresponds to the results of *f5p* model space without CP effects, the dot line represents the results of the CP effects with M3Y interaction, the solid curve shows the CP effects with MSDI interaction.

1. The 0.771 MeV $3/2^- \rightarrow 1/2_1^-$ state

The study of odd-A nuclei near close shell has been very important due to the particularly simple structure of their excitation spectra. Especially nuclei were with a few particles (or holes) outside a closed core shell. In this transition, the electron excites the nucleus from the ground state ($3/2^-$ 7/2) to the excited state ($1/2_1^-$ 7/2), with excitation energy 0.771 MeV. To obtain a first impression of the quality of the model descriptions, the reduced transition probability was calculated B(C2↑) without including CP effects (11.72 e^2fm^4) fails to describe the experimental data. The inclusion of CP effect enhances the B(C2↑) value, MSDI calculated value (88.37 e^2fm^4), which is closer to the experimental data (89(3) e^2fm^4)[28], than that calculated by M3Y (73.29 e^2fm^4). The reduced transition probabilities for 65Cu nucleus are shown in Table 1.

Fig.1 shows the calculations of longitudinal C2 form factors for transition $3/2^- \rightarrow 1/2_1^-$. The calculation form factors with and without CP effects compared with the experimental data, which are taken from Ref. [28]. The mode space *f5p* calculations form factors without CP effects failed to describe the experimental data. The calculation form factors with taking the CP effects into account through particle-hole excitations up to $6\hbar\omega$, using MSDI as a residual two body interaction reproduces the data very well until momentum transfer q=2.1 fm^{-1}. The form factors with the core-polarization effects using realistic M3Y interaction reproduce the experimental data very well at the first and the third maximum until q=2.25 fm^{-1}. The second maximum underestimates the experimental data by a factor of about 5 at q region (1.4-1.8 fm^{-1}). The first diffraction minimum position shifted to higher q values. In general, in this transition the form factor with CP effect using MSDI as residual interaction describe the experimental data better than using M3Y realistic interaction.

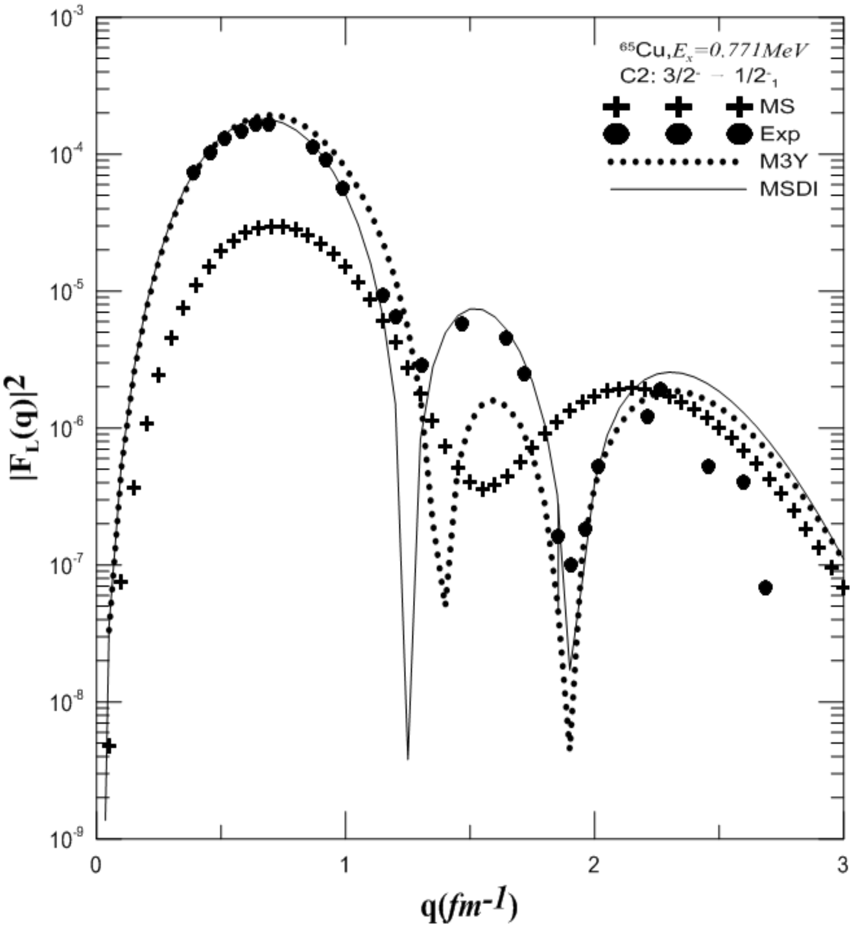

***Fig.1:** Inelastic longitudinal form factors for C2 transition $3/2^- \rightarrow 1/2_1^-$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to 6ħω. The experimental data are taken from Ref. [28].*

2. The 2.213 MeV $3/2^- \rightarrow 1/2_2^-$ state

In this transition, the electron excites the nucleus from the ground state $j_i^\pi T_i$=(3/2⁻ 7/2) to the state $j_f^\pi T_f$ =($1/2_2^-$ 7/2) with 2.213 MeV excitation energy. The reduced transition probability B (C2↑) calculated without including CP effect (0.2989 e^2fm^4) fails to describe the experimental data (0.71 (23) e^2fm^4) [28]. The inclusion of CP effects overestimate the B(C2↑) value. The MSDI calculated value (4.536 e^2fm^4) and the M3Y value (3.961 e^2fm^4).

The theoretical electron scattering form factors without and with CP effects using MSDI and M3Y interaction is displayed in Fig. 2. The model space calculation underestimated the form factors at all momentum transfers, but give the diffraction minimum at correct position.

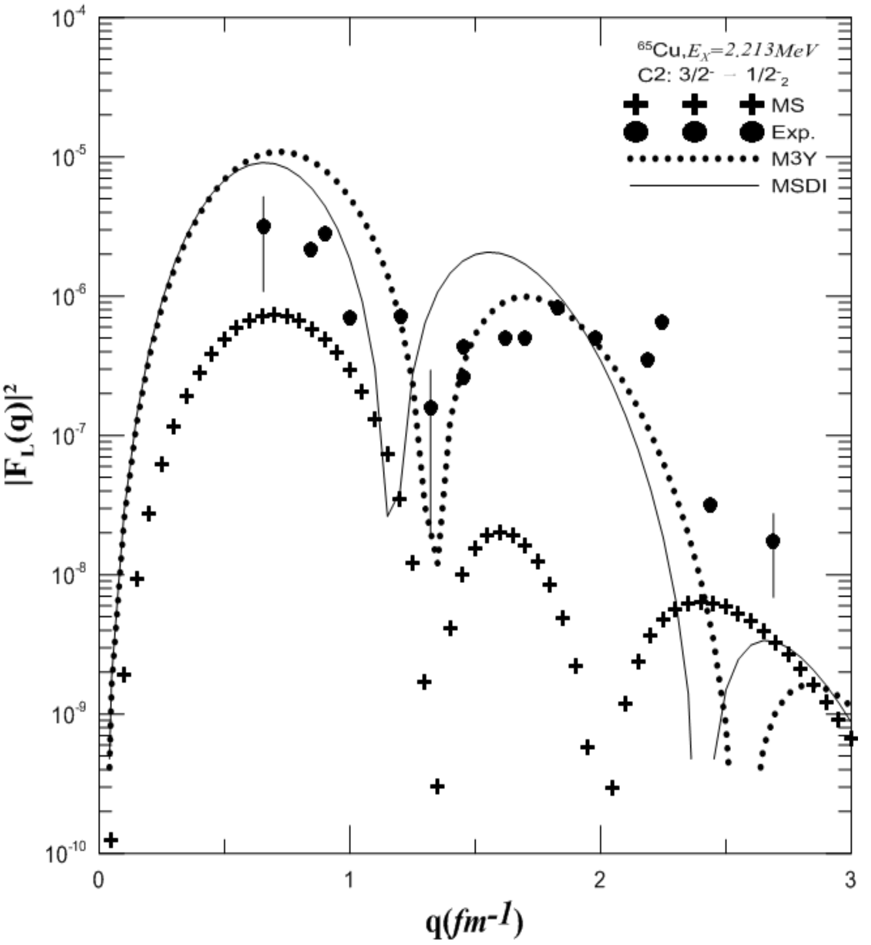

Fig.2: Inelastic longitudinal form factors for C2 transition 3/2⁻ →$1/2_2^-$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to 6ħω. The experimental data are taken from Ref. [28].

While the model space with the core effects using MSDI interaction gives the shape of the form factor, but it is overestimated the experimental data in the first and second maximums and underestimated experimental data in the third maximum.

The calculated electron scattering form factors using M3Y interaction produce the shaped very well, but overestimated the experimental data on the first maximum. And also gives the first diffraction minimum at the correct momentum transfer, but shift the second minimum to high momentum. In the momentum transfers region *q<1* the form factor with CP effect using MSDI interaction describe the experimental data better than using M3Y interaction, while in the other momentum transfers regions the form factor with CP effect using M3Y interaction describes the experimental data better than using MSDI interaction.

3. The 1.725 MeV 3/2⁻ → $3/2_2^-$ state

The ($j_i^\pi\ T = 3/2_2^-\ \ 7/2$) state has an excitation energy of 1.725 MeV. The calculated B(C2↑) value without including CP effects are equal to (3.339 e^2fm^4), which is low in comparison with the measured value (11(1) e^2fm^4) [28]. When the CP effects are included, the B(C2↑) with MSDI becomes (7.947 e^2fm^4), which is nearly close to measured value better than M3Y(4.146 e^2fm^4), as illustrated in the Table 1. In the momentum transfers region q<1.4 the result with

CP effect using MSDI interaction worse than the results without CP effect using MSDI interaction.

The longitudinal C2 form factors for ^{65}Cu nucleus for this transition using MSDI and M3Y interaction as residual interactions are displayed in Fig. 3 in comparison with experimental data of [28]. The model space calculations underestimate the experimental data in all *q* values and the inclusion of the core effect with MSDI interaction enhances the calculations. In this case, the data are well described for $1.25 \le q \le 1.7\ fm^{-1}$, for higher *q* value the calculations overestimated the experimental data. The inclusion of the core with the M3Y interaction gives the shape very well in the first peak, yet the curve is underestimated by a factor of about 0.5, and the second peak shifted toward the high momentum transfer *q*. In general, in this transition results using M3Y interaction describe the experimental data better than results with using MSDI interaction in the all momentum transfers regions.

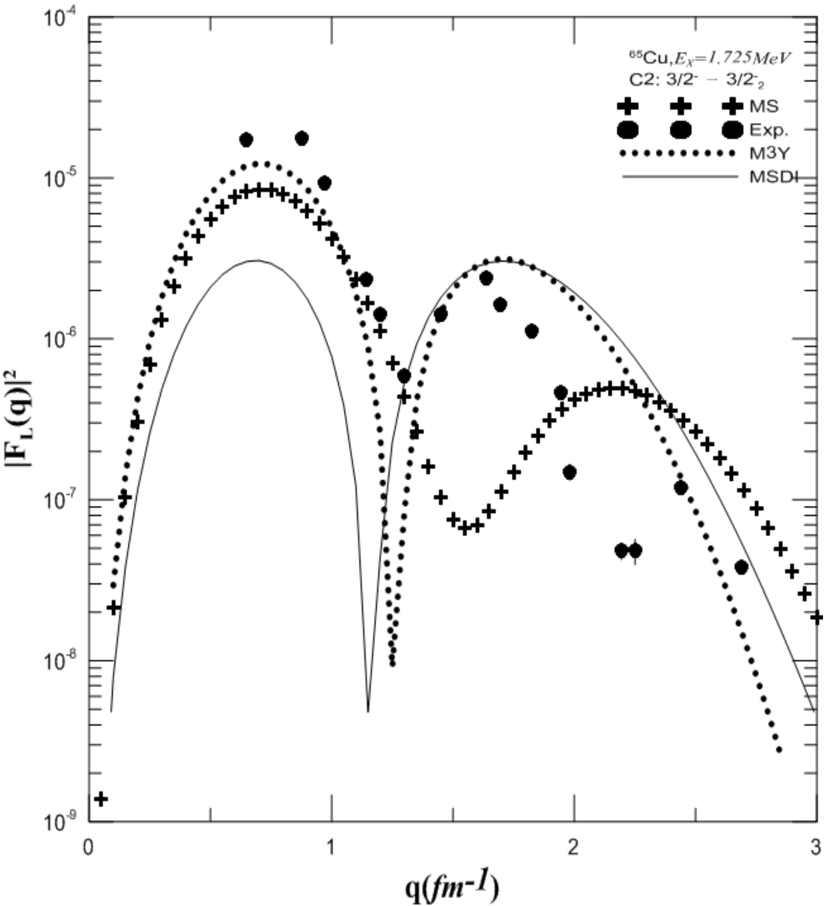

***Fig.3:** Inelastic longitudinal form factors for C2 transition $3/2^- \rightarrow 3/2_2^-$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to $6\hbar\omega$. The experimental data are taken from Ref. [28].*

4. The 2.327 MeV $3/2^- \rightarrow 3/2_3^-$ state

In this transition, the ^{65}Cu nucleus is excited from the ground state ($3/2^-$ 7/2) to the state ($3/2_3^-$ 7/2) with the excitation energy of 2.327 MeV. The experimental B(C2↑) is equal to 7.0(9)e^2fm^4 [28], while the theoretically calculated one is equal to 0.0267 e^2fm^4 for model space, which is low in comparison with the measured value. When the CP effects are included, the B(C2↑) becomes (1.241e^2fm^4) for MSDI, which is lower than the experimental values, and

(3.536 $e^2 fm^4$) for M3Y, which it is the nearest to the experimental values.

The calculations electron scattering form factors using MSDI interaction are displayed in Fig.4, the theoretical calculations, including the model space only does not give both the shape and the diffraction minimum of the form factor.

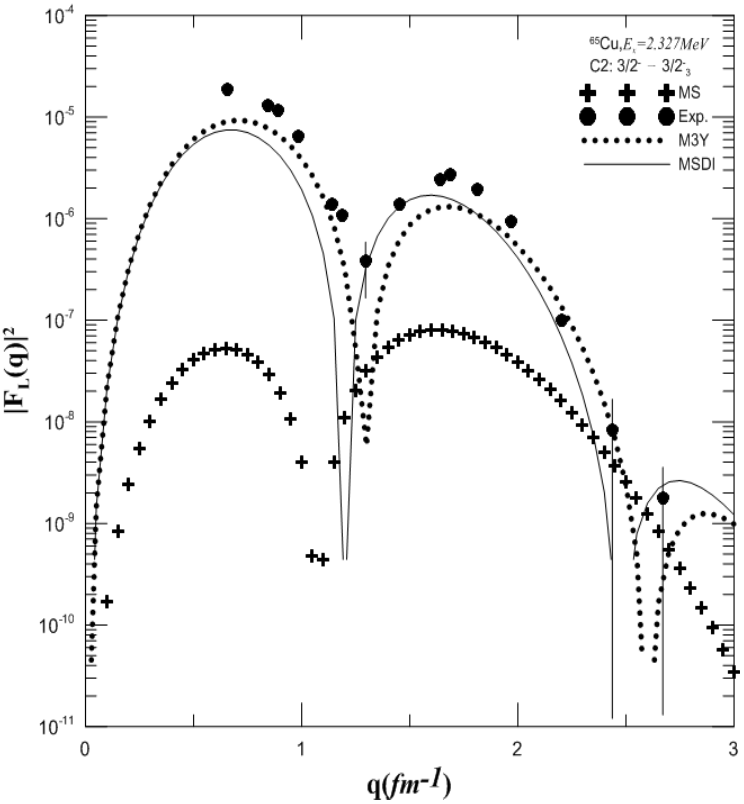

Fig.4: Inelastic longitudinal form factors for C2 transition $3/2^- \rightarrow 3/2^-_3$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to 6ħω. The experimental data are taken from Ref. [28].

While the model space with the core effects using MSDI interaction gives the exact shape of the form factor and the diffraction minimum, but it is still underestimated in the first maximum. The second maximum and the diffraction minimum reasonably well reproduced the experimental data. The theoretical electron scattering form factors using M3Y interaction (dot line) seems to be shaped very well, but slightly underestimated the experimental data in the first and second maximum.

5. The 1.116 MeV $3/2^- \rightarrow 5/2^-_1$ state

The ($5/2^-_1$ 7/2) state of the ^{65}Cu nucleus has an excitation energy of 1.116 MeV. Table 1 displays the calculated B(C2↑) value without including CP effects is equal to 2.881$e^2 fm^4$, when the CP effects are included, the B(C2↑) becomes to MSDI(3.442$e^2 fm^4$) and to M3Y equal (93.24$e^2 fm^4$), which are low in comparison with the measured value 289(5)$e^2 fm^4$[28].

Fig.5 shows the calculations of longitudinal C2 form factors of *f5p* model space with and without CP effects compared with the experimental data [28]. The model space gives the shape of the form factor and the diffraction minimum of the experimental data of considered nucleus at the correct momentum transfer, but underestimated the experimental data. The calculations of longitudinal C2 form factors of the *f5p*-shell model with taking the CP effects into account using the MSDI interaction have a good agreement with the experimental data in the second maximum at the region $1.25 \leq q \leq 2.1 fm^{-1}$ of the momentum transfer but underestimated the experimental data by about of the factor 4 in the first and third maximums. When the realistic M3Y interaction is used, the calculations form factors are in agreement with the experimental data in shape and local the diffraction minimum at the correct momentum transfer, but it is underestimated the experimental data by about of the factor 4 in the first and second maximum.

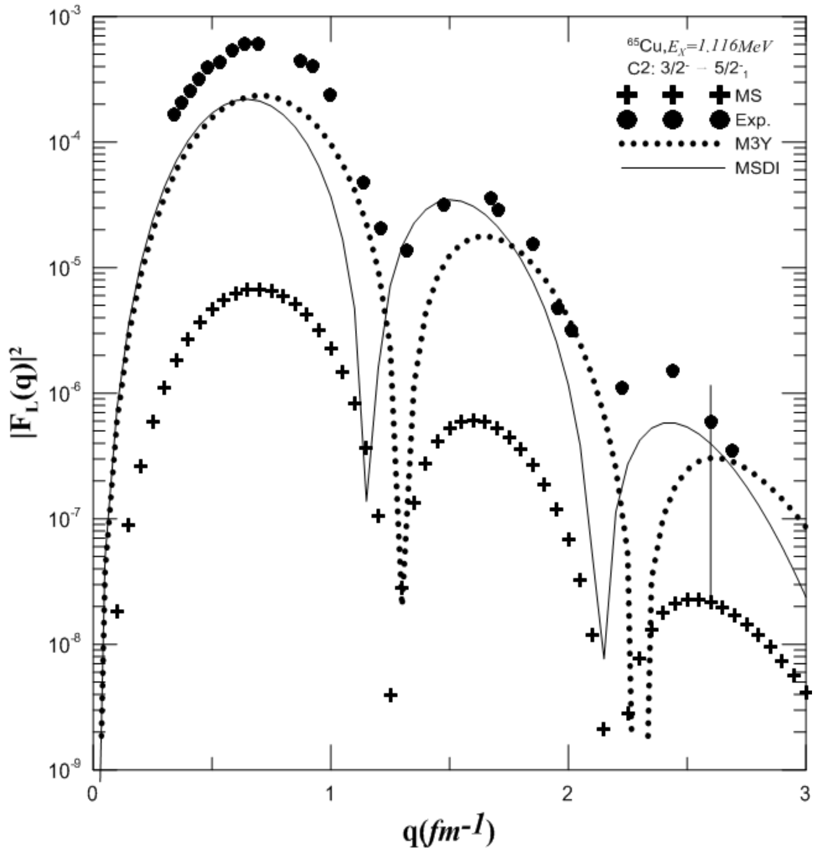

***Fig.5:** Inelastic longitudinal form factors for C2 transition $3/2^- \rightarrow 5/2_1^-$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to $6\hbar\omega$. The experimental data are taken from Ref. [28].*

6. The 1.624 MeV $3/2^- \rightarrow 5/2_2^-$ state

In this transition, the electron excites the nucleus from the ground state j_i^π T$_i$ = ($3/2^-$ 7/2) to the state j_f^π T$_f$ =($5/2_2^-$ 7/2) with excitation energy of 1.624 MeV. The calculated B(C2↑) value 3.311e^2fm^4 for the model space and (3.898 e^2fm^4)for calculating with M3Y which less than the measured value (6.01(52) e^2fm^4) [28]. The MSDI value (118.6e^2fm^4) is very larger than the experimental values as shown in Table 1. The calculation form factors with and without core effects are shown in Fig.6. In this figure the model space calculation fails to describe the experimental data [28] and it also failed to describe the location of the diffraction minimum in the correct *q* values.

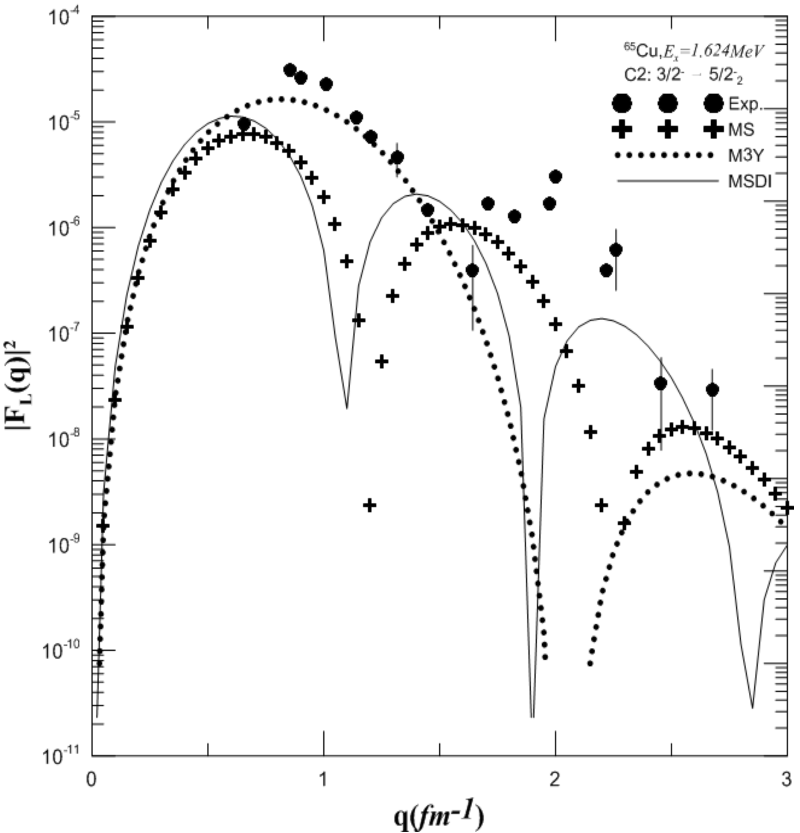

Fig.6: Inelastic longitudinal form factors for C2 transition 3/2$^-$ →$5/2_2^-$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to 6ħω. The experimental data are taken from Ref. [28].

The C2 form factors with the CP effects using MSDI interaction (double dot dash line) as a residual interactions underestimated the experimental data for the whole momentum transfer and shifted toward lower *q* values. The calculation results using M3Y achieve good agreements with the experimental data on the first maximum and it's gave the diffraction minimum at correct q values. The second maximum underestimates the experimental data, especially for $q \geq 1.7\ fm^{-1}$, and shifted toward higher *q* values. In general, in this transition results using M3Y interaction describe the experimental data better than results with using MSDI interaction in often momentum transfers regions.

7. The 1.482 MeV 3/2$^-$ → 7/2$^-$ state C2 transition

The ^{65}Cu nucleus is excited from the ground state (3/2$^-$ 7/2) to the state (7/2$^-$ 7/2) with the excitation energy of 1.482 MeV. The calculated B(C2↑) value without including CP effect is equal to 2.145 e^2fm^4, which is low in comparison with the measured value 315(5) e^2fm^4 [28]. When the CP effects are included, it becomes for MSDI (193.6 e^2fm^4) and to M3Y (150.6 e^2fm^4), which is increasing, but smaller than the measured value as shown in the Table1. Fig.7 shows the calculations of longitudinal C2 form factors with and without CP effects compared with the experimental data which are taken from Ref. [28]. The *f5p* model space calculations form factors failed to describe the experimental data. The calculation form factors with taking the CP effects into account using MSDI residual interaction reproduces the data well only in the first maximum. The minimum diffraction of scattered electrons slightly shifted toward smaller *q* values. The form factors with the CP effects using realistic M3Y interaction reproduces the experimental data shape but underestimates the experimental data by about of factor 2. Also the second diffraction minimum position shifted to higher *q* values.

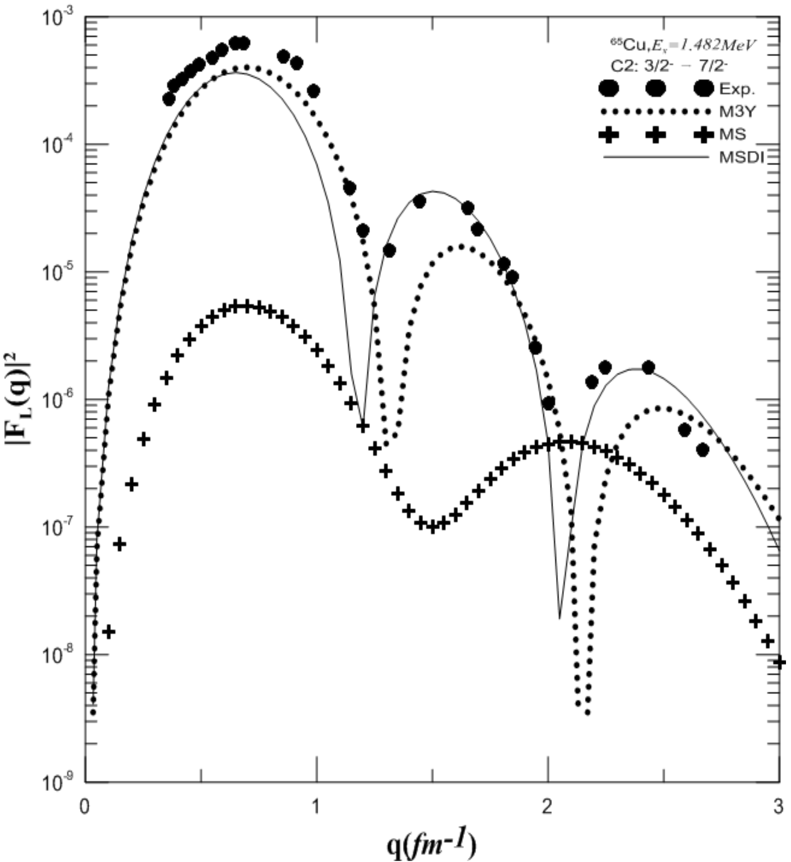

Fig.7: Inelastic longitudinal form factors for C2 transition 3/2⁻ →7/2⁻ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to 6ħω. The experimental data are taken from Ref. [28].

8. The 2.278 MeV 3/2⁻ → 7/2⁻ state C4 transition

In this case, the incident electron excites the ^{65}Cu nucleus from the ground state ($3/2^-$ 7/2) to the state ($7/2^-$ 7/2) with excitation energy of 2.278MeV. The calculated B(C4↑) value without including CP effect is equal to 92.09 e^2fm^8, when the CP effects are included, it becomes to MSDI (11620 e^2fm^8), and to M3Y (5829 e^2fm^8).

The C4 electron scattering form factors with and without of core effect displayed in Fig.8, the calculated result includes the model space brought the shape and the diffraction minimum, but underestimated the experimental data. While the model space with CP effects with MSDI residual interaction gives the exact shape and the diffraction minimum of the C4 form factors in all regions of momentum transfer. The longitudinal C4 form factors for ^{65}Cu nucleus using M3Y interaction as residual interaction enhances the calculations. In this case, the data are well described for $q \leq 1.0$ fm^{-1}, also for higher *q* value in the first maximum the calculations are slightly overestimated the experimental data.

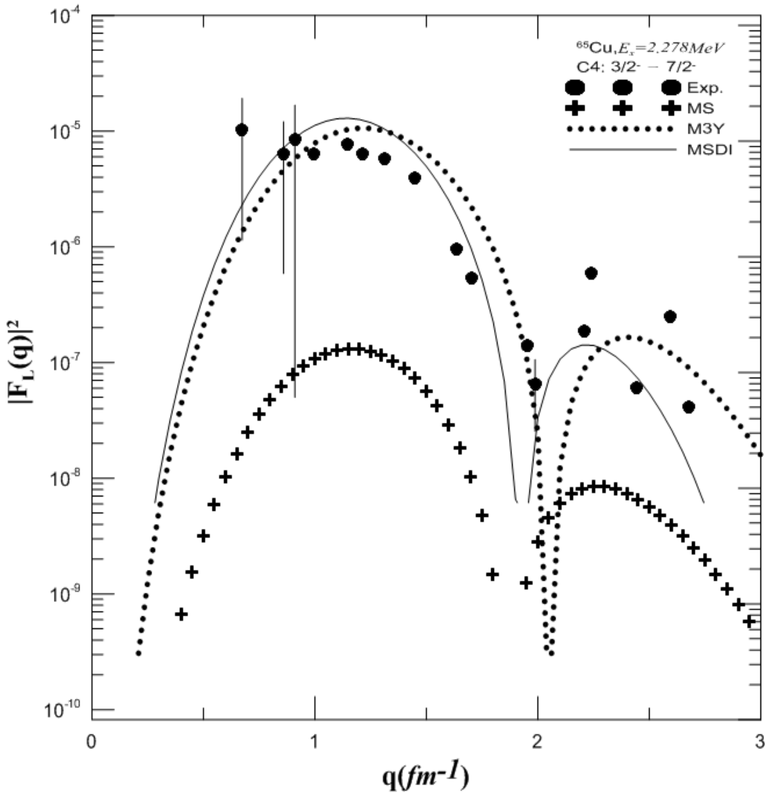

Fig.8: Inelastic longitudinal form factors for C4 transition $3/2^-$ → $7/2^-$ in ^{65}Cu nucleus using MSDI and M3Y interactions with core-polarization effects, through particle-hole excitations up to 6ħω. The experimental data are taken from Ref. [28].

Table 1: Theoretical calculations of the reduced transition probabilities B ($CL,0^+ \rightarrow L$) in units of e^2 fm^{2L} in comparison with experimental values for ^{65}Cu nucleus transitions.

$J_i^\pi T_i$	$J_f^\pi T_f$	**E$_x$MeV**	**B(C2),B(C4)**			
			Th.			**Exp.[28]**
			MS	**MSDI**	**M3Y**	
				MS+CP	**MS+CP**	
$3/2^-$ 7/2	**$(1/2^-)_1$ 7/2**	0.771	11.72	88.37	73.29	89(3)
$3/2^-$ 7/2	**$(1/2^-)_2$ 7/2**	2.213	0.2989	4.536	3.961	0.71(23)
$3/2^-$ 7/2	**$(3/2^-)_2$ 7/2**	1.725	3.339	7.947	4.146	11(1)
$3/2^-$ 7/2	**$(3/2^-)_3$ 7/2**	2.327	0.0267	1.241	3.536	7.0(9)
$3/2^-$ 7/2	**$(5/2^-)_1$ 7/2**	1.116	2.881	3.442	93.24	289(5)
$3/2^-$ 7/2	**$(5/2^-)_2$ 7/2**	1.624	3.311	118.6	3.898	6.01(52)
$3/2^-$ 7/2	**$7/2^-$ 7/2B(C2)**	1.482	2.145	193.6	150.6	315(5)
$3/2^-$ 7/2	**$7/2^-$ 7/2B(C4)**	2.278	92.09	11620	5829	.....

Conclusions

In this work the shell model calculation was executed in $1f_{5/2}$,$2p_{3/2}$,$2p_{1/2}$ orbital's. The C2 and C4 transitions without CP effect for ^{65}Cu nucleus are less successful to produce the experimental data. The result can be enhanced when the CP are taken into account, up to *6ħω* and describe the experimental data better than those of the *f5p* model space calculation. To some extent the calculation form factors with MSDI and M3Y interactions reproduces the experimental data very well in all transfer momentum for all transitions under consideration. In addition to that, all CP effect calculations have no adjustable parameters or any enhancement factors.

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