**Longitudinal electron scattering form factors for 50,52,54Cr**

**A.D.Salman**

*Department of Physics, College of Science, University of Karbala, Iraq*

**N.M.Adeeb**

*Department of Physics, College of Science, University of Baghdad, Iraq*

**M.H.Oleiwi**

*Department of Physics, College of Education, University of Babylon, Iraq*

**Abstract**.

The form factor for inelastic electron scattering to 2+ and 4+ states in 50,52,54Cr have been studied in the framework of shell model. The calculation is performed in the (0f7/2,1p3/2,0f5/2,1p1/2). Longitudinal C2 and C4 multipolarity are investigated for these states. Core polarization effect are included through the first order perturbation theory and the matrix element are calculated with MSDI. The inclusion of core polarization leads to an enhancement of the calculated form factor, improving good agreement with experimental data.

**الخلاصة:**

تم حساب عوامل تشكل الاستطارة الطولية غير المرنة C2 و C4 للانتقالين 2+ و 4+ للنوى50,52,54Cr في إطار أنموذج القشرة. الحسابات أنجزت في فضاء الأنموذج (0f7/2,1p3/2,0f5/2,1p1/2) . الحسابات تضمنت إدخال تأثير استقطاب القلب من خلال المرتبة الأولى لنظرية الاضطراب وحسبت عناصر المصفوفة باستخدام جهد دلتا السطحي المحور(MSDI).إن إدخال تأثيرات استقطاب القلب يؤدي إلى تطابق جيد مع النتائج العملية**.**

**1. Introduction**

The calculations of shell model, carried out within a model space in which the nucleons are restricted to occupy a few orbits are unable to reproduce the measured static moments or transition strengths without scaling factors. Comparison between calculated and measured longitudinal electron scattering form factors has long been used as stringent tests of models for transition densities. Various microscopic and macroscopic theories have been used to study excitations in nuclei (Sato *et al*.,1985). Shell model within a restricted model space is one of the models, which succeeded in describing static properties of nuclei, when effective charges are used**.** Calculations of form factors using the model space wave function alone is inadequate for reproducing the data of electron scattering (Booten *et al*.,1994). Therefore, effects out of the model space, which are called core polarization effects, are necessary to be included in the calculations. The intermediate one-particle one-hole states are taken up to  excitation. These effects are found essential for obtaining a quantitative agreement with the experimental data (Yokoyama *et al*.,1989;Sato *et al.,*1994). A microscopic model (Radhi *et al*.,2001;Radhi,2003) has been used in order to study the core polarization effect on the longitudinal form factors of fp-shell nuclei. The auther adopted the first order core polarization to calculate the C2 form factors of the fp-shell nuclei. Inelastic Electron Scattering from fp shell nuclei had been studied by [Sahu](file:///I:\nsrsearch.cgi?author=Sahu) *et al* (Saho *et al*.,1986). They calculated form factors for , , , , and  by the use of Hartree-Fock theory, their results are in a good agreement with the experimental data. The form factors for the inelastic electron scattering to 2+, 4+ and 6+states in ,  and  were studied by Sahu (Saho *et al*.,1990;Saho *et al*.,1987) in the framework of the Hartree-Fock model, also the calculation is performed in the 1f7/2, 2p3/2, 1f5/2, 2p1/2 model space using a modified Kuo-Brown effective interaction. Magnetic dipole excitation of N = 28 isotones , , ,  and , was studied by Muto and Horie (Muto *et al*.,1985), in terms of the shell model by assuming configurations with m = 0, 1 and 2 on an inert  core. The aim of present work is to use a realistic effective nucleon-nucleon (NN) interaction as a residual interaction to calculate the core polarization (CP) effects through a microscopic theory, with a selection of model space effective interaction which generates the model space wave functions(shell model wave functions) and highly excited states. The (MSDI) were used in this case as a residual interaction. The strength of the MSDI denoted by AT ,B and C are set equal to A0=A1=B= 6.2 MeV and C=0. The single particle wave function were those of the harmonic oscillator potential (HO) with size parameter *b* chosen to reproduce the measured ground state root mean square charge radii of these nuclei. The one-body density matrix (OBDM) elements () are calculated using the shell model code OXBASH (Brown *et al*.**,**2005)

**2. Theory**

The electron scattering form factor for a given multipolarity and momentum transfer  is expressed as (de Forest,1966)

 ……..(1)

Where  is the finite nucleon-size correction and  is the center of mass correction,  is the mass number and *b* is the harmonic oscillator size parameter.

The effect of the core polarization on the form factors is based on a microscopic theory, which combines shell-model wave functions and configuration with higher energy as particle-hole perturbation expansion. The reduced matrix element of the electron scattering operator is expressed as a sum of the fp-model space (fp) contribution and the core-polarization (cp) contribution, as follows (Radhi *et al*.,2001)

 …..(2)

with  selection the longitudinal (L), electric(E) and magnetic(M) transverse form factors, respectively. The Greek symbols were used to denote quantum numbers in coordinate space and isospace, i.e.  ,  and . The fp-shell model space element can be expressed as linear combination of the single-particle matrix element (Wildenthal,1989)

 …..(3)

where  are the structure factors (one body density matrix element), given by,

 …..(4)

The  and  label are single-particle states for the fp-shell model space. Similarly, core-polarization matrix element as follow:

 …..(5)

Up to the first order perturbation theory, the single-particle matrix element for the higher-energy configuration is given by(Ellis et al.,1971)



.…..(6)

The operator Q is the projection operator on the space outside the model space. and  are the energies of initial and final states. For the residual interaction  the MSDI were adopted.

The two term in right hand side of Eq.(6) can be written as (Brussard,1977)



…..(7)

Where runs over particle states and  over hole state and  is the single-particle energy . The hole states cover all core orbits.

****

…..(8)

With  and 

The electric transition strength is given by,



Where k = Ex /ћc .

**3. Results and discussion**

**3.1. The nucleus 50Cr**

The structure and properties of 50Cr are experimentally and theoretically well studied. For the conventional multiparticle shell-model, 50Cr has ten nucleons outside the core 40ca and it is possible to perform shell-model calculations for this nucleus in 2p1f shell space. The calculation in the 2p1f space assumes an inert 40Ca core.

The two transitions under investigation are C2, 0.78MeV (0+ 1 2+1) and C4, 2.675MeV (0+ 1 4+1). The calculated *B(C2)* and *B(C4)* from the present work in comparison with experimental values are displayed in table (1).

**3.1.1 The 0.78 MeV (2+ 1) state**

In this transition, the electron excites the nucleus from the ground state (0+1) to the state (2+1) with excitation energy of 0.78 MeV. In fig.(1) the experimental data of the C2 Coulomb form factors which are taken from Ref. (Saho *et al*.,1990) are compared with the theoretical pf-shell model calculation. The solid curve shows the result with core-polarization effects and the dashed curve corresponding to the result without core polarization effects (pf- shell model space only). We are observed three peaks in the form factors in this nucleus. In the present of core polarization effect, the first peak is in good agreement with experimental data, but the second peak is overestimated and the third peak is underestimated. In pf-shell model, the calculated form factors underpredict the data in all regions of momentum transfers q, as shown in fig.(1) by dashed curve. In this model only model space wave function are considered. The pf-shell fail to describe the data in form factors. Core polarization effects enhance the form factor and reproduce the measured form factor up to q=1.1 fm-1 as shown by solid curve of fig.(1).

Sahu et al. (Saho *et al*.,1990) have measured the form factors for the transition 0+ 2+ up to momentum transfers q=3 fm-1. They also observed three peaks in the form factor in this nucleus. They found that the experimental data are good agreement with calculated form factor within Hatree-Fock model.



Fig.(1) Inelastic longitudinal form factors for the transition to the2+ in the 50Cr. The experimental data are taken from ref. (Sahu *et al*.,1990 )

**3.1.2. The 2.675 MeV (4+ 1) state**

The form factor for C4 transition in 50Cr with an excited energy 2.675 MeV is displayed in fig.(2), where the solid curve represent the model space with the effect of core polarization, the dashed curve represent the model space and the experimental data represented by points. The data are well reproduced for first lobe, and also up to q=1.4fm-1. For 1.4<q<2 fm-1 the calculated form factors is overestimated and shifted toward higher q values. As shown in fig.(2) the second maximum in underestimated. When the core polarization effect is included we get a reasonable agreement between calculated data and experiment for the first maximum, but fail to describe the form factors for the second maximum. The model space fail to describe the data in the form factors for all momentum transfers. Raina et al. ( Raina *et al*.,1988) were also unable to reproduce the second maximum for 50Cr within their projected Hartree-Fock-Bogolinbov formalism , where we get a similar result.



Fig.(2) Inelastic longitudinal form factors for the transition to the4+ in the 50Cr,the experimental data are taken from ref. (Raina,1988)

**3.2 The nucleus 52Cr**

For Chromium fifty two the core is considered as 48Ca and four particles are distributed over 2p1f-shell model space. Two transitions are considered in this work, namely:

C2, 1.43MeV (0+ 2 2+ 2) and C4, 2.600MeV (0+ 2 4+ 2). The calculated *B(C2)* and *B(C4)* from the present work in comparison with experimental values are displayed in table (1).

**3.2.1. The 1.43 MeV (2+ 2) state**

The nucleus is excited from the ground state (0+ 2) to the state (2+2) with an excitation energy 1.43 MeV. Fig.(3) shows the calculated longitudinal Coulomb C2 electron scattering form factor as a function of momentum transfers q. The dashed curve represents the results of 2p1f-shell, while the solid curve represents the results of 2p1f-shell with the inclusion of core polarization effects. For this nucleus, the form factor show three peaks. The first peak occurs at 0.7 fm-1, the second at q=1.7fm-1 and the third peak at q=2.6fm-1. The first peak is reasonably well reproduced within our calculation up to momentum transfers q=1 fm-1. The second peak is overestimated, but the third maximum is quenched. In general the behavior qualitatively is in a good agreement with the experiment. The 2p1f-shell model fail to describe the data in all momentum transfers and the inclusion of cp effects enhance the form factor. Sahu et al. (Sahu *et al*.,1990) also observe three peaks in the form factor in these nucleus, where they observe that the first two peaks are reasonably well reproduced within Hartree-Fock model, but the third is overestimated.



Fig.(3) Inelastic longitudinal form factors for the transition to the2+ in the 52Cr.The experimental data are taken from ref .(Sahu *et al*.,1990)

**3.2.2. The 2.600 MeV (4+2) state**

Fig.(4) compares the calculated and observed form factor for the 0+ 4+ transition of nucleus 52Cr with inclusion of cp effect as shown by solid curve and that without cp effect as shown by dashed curve in fig.(4). The agreement between the experimental data and the result of 2p1f-shell model with the inclusion of cp effect in the region of q<1.5 fm-1 is quite good both in behavior and magnitude. There may be some disagreement with the experimental data in the region of q> 1.5fm-1, where the position of the first minimum is shifted toward higher momentum transfers and the calculation underestimated the magnitude of form factors around its second maximum. The 2p1f-shell model space well reproduce the second maximum, the first maximum is underestimated as shown by dashed curve in fig.(4). Raina et al. observed similar behavior within the projected Hartree-Fock- Bogolinbov formalism (Raina *et al*.,1988).



Fig.(4) Inelastic longitudinal form factor for the transition to the4+ in the 52Cr. The experimental data are taken from ref.(Raina *et al*.,1988)

*)*

**3.3. The nucleus 54Cr**

**C**hromium 54Cr has been extensively studied both theoretically and experimentally. For the conventional many particle shell model, this nucleus is considered as an inert 48Cacoreplussix nucleons distributed over 2p1f space. The calculations are presented for following transitions C2,0.84 MeV (0+3 2+3) and C4, 0.832 (0+3 4+3) . The calculated *B(C2)* and *B(C4)* from the present work in comparison with experimental values are displayed in table (1).

**3.3.1. The 0.84 MeV (2+3) state**

The form factor for C2 transition in 54Cr with an excitation energy 0.84 MeV, when the electron excite the nucleus from ground state (0+3) to (2+3) state. A good results to the 54Cr data is obtained with the 2p1f-shell model calculations including cp effects in either first or third maxima, but the second maximum is overestimated as shown in fig.(5) by solid curve. In all region of momentum transfers the form factor is predicted very well in shape. Sahu et al (Sahu *et al.*,1990) have measured the form factors for the transition 0+ 2+ for 54Cr up to momentum transfers 3fm-1. They also observed three peaks in the form factors in this nucleus. They found that that the data could be available within Hartree-Fock model for the first and second maxima, but the third maximum is overestimated. In our calculation we get a good fit between calculated and experimental form factors for the third maximum. The model space fail to describe the form factors in all momentum transfers, so the present of cp effect enhance the form factor.



Fig.(5) Inelastic longitudinal form factors for the transition to the2+ in the 54Cr, the experimental data are taken from ref.(Sahu *at al*.,1990)

**3.3.2. The 0.832 MeV (4+3) state**

In this state the electron excite the nucleus from ground state (0+ 3) to the excited state (4+ 3). Two peaks we observe as shown in fig.(6)with and without cp effect. It is seen that the present calculation is quite successful in reproducing the magnitude of the form factors at the first maxima with inclusion of cp as shown in fig.(6) by solid curve. However , one observe discrepancies in the momentum transfers range 1.8<q<2.6 fm-1, the calculation overestimate the magnitude of the form factors around its second maximum. Raina et al. (Raina *et al*.,1988) observe the position of the first minimum is shifted towards higher momentum transfers and the calculation underestimated the magnitude of form factor around its second maximum within their projected Hatree-Fock-Bogoliubov formalism. As shown in fig.(6) the 2p1f-shell model space calculation fail to describe the data in all the region of momentum transfers, so the inclusion of cp effect lead to an enhancement in the calculation of the form factors.



Fig.(6) Experimental and calculated form factor for the transition to the4+ in the 54Cr. The experimental data are taken from ref.(Raina *et al*.,1988)

*)*

***Table(1):Theoretical calculations of the reduced transition probabilities B(C2) (in units) and B(C4) (in units of ) in comparison with experimental values.***

│*F*(*q*)│2

│*F*(*q*)│2

│*F*(*q*)│2

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Nucleus |  |  |  |  |  | *fp* | *fp+cp* | Exp.[Ref.] |
| *50Cr* |  |  |  |  |  |  |  |  |
| *Cr52* |  |  |  |  |  |  |  |  |
| *54Cr* |  |  |  |  |  |  |  |  |

**4. Conclusions**

The fp-shell models, which can describe static properties and energy level are less successful in describing dynamic properties such as C2 and C4 transition rates and electron scattering form factors. The inclusion of higher-excited configurations by means of cp enhances the form factors and brings the theoretical results closer to the experimental data.

**5. Acknowledgment**

The authors would like to express their thanks to Prof. Raad A. Radhi for providing them with the Fortran code for calculating the core – polarization effect. One of the auther M. H. Oleiwi are greatfully acknowledged Dr. Fouad A. Majeed for reading the manuscript and correction he made to it.

**References:**

# Booten J. G. L. and Van Hees A. G. M.:**(**1994**)** Nucl. Phys. A569 510.

Brown B.A., Etchegoyen A., Godwin N.S., Rae W.D.M., Richter W.A., Ormand W.E., Warburton E.K., Winfield J.S., Zhao L. and C.H., (2005), Zimmerman MSU-NSCL report number 1289.

Brussaard P.J., Glaudemans P.W.M.," (1977), Shell Model Application in Nuclear Spectroscopy", North-Holland, Amsterdam.

de Forest T., jr and Walecka J. d., (1966), Adv. Phys. 151.

Ellis P.J. and Mavromattes H.A.; (1971), Nucl. Phys.A175309.

Lightbody J. W., et al, (1983), Phys. Rev., C27,113.

MutoK. and Horie H., (1985),[Nucl. Phys. A](file:///I:\science\journal\03759474)440, 254.

Radhi R.A. , A. A., Abdullah Z. A. Dakhil and Adeeb N. M., (2001) Nucl. Phys.A696442.

Radhi R.A., (2003), Nucl. Phys. A716100

Raina P. K. and Sharma S. K., (1988), Phys. Rev. C371427.

Sato T., Koshigiri K. and Ohtsubos H. (1985),: Z. Phys., A320 507 .

Sahu [R.](file:///I:\nsrsearch.cgi?author=Sahu) , Ahalpara [I:\nsrsearch.cgiD. P.](file:///I:\nsrsearch.cgi?author=Ahalpara)  andBhatt [K. H.](file:///I:\nsrsearch.cgi?author=Bhatt)  (1986), Bull.Am.Phys.Soc. 31, No.10, 1764, DC7.

Sahu R., Ahalpara [D. P.](file:///I:\nsrsearch.cgi?author=Ahalpara)  and Bhatt [K. H. (1990)](file:///I:\nsrsearch.cgi?author=Bhatt) , J. Phys. (London) G16, 733.

Sahu*,R.* [D. P. Ahalpara](file:///I:\nsrsearch.cgi?author=Ahalpara) and Pandya [S. P.](http://cdfe.sinp.msu.ru/cgi-bin/muh/nsrsearch.cgi?author=Pandya)  *(1987)*, J. Phys. (London) *G13, 603.*

Sato T., N., Odagawa H. Ohtsubo, and Lee T. S. H. (1994) , Phys. Rev. C49776.

Towsley C.W., Cline D. and Horoshko R. N. (1975), Nucl. Phys. A250,381.

Wildenthal B.H.; (1984) ,Prog Part Nucl.Phys,115.

Yokoyama A. and Ogawa K. (1989); Phys. Rev. C392458.