Volume 1 No. 3, September 2011 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

Longitudinal form factor for some sd-shell nuclei using large scale model space

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ABSTRACT

Electron scattering form factors have been calculated for some sd-shell nuclei using large scale model pace includes the *sd-pf* model space includes the $2s_{1/2}, 1d_{5/2}, 1d_{3/2}, 2p_{3/2}, 2p_{1/2}, 1f_{7/2}$ and $1f_{5/2}$ valance orbits. The two body interaction started from the Wildenthal "USD" (*sd*) interaction and the van Hees-Glaudemans (*fp*) interaction, which were connected by the cross-shell Millener-Kurath interaction. The calculation performed by using the shell model code OXBASH with Skyrme-Hartree Fock (Skx) and Harmonic Oscillator (HO) potential to calculate the single particle wave function.

Keywords: *sd-shell nuclei, (e,e) inelastic longitudinal form factors, calculation with model space including core-polarization effects.*

1. INTRODUCTION

Effective two-body interactions have been extremely successful for light nuclei and have provided essentially much of the quantitative predictive power of large-basis shell-model calculations. The best large-scale example is the USD interaction of Wildenthal which we have successfully used to understand the properties of sd-shell nuclei between A=16 and 40 [1,2]. Approximately 3000 levels below 10 MeV are predicted in this model. The sd-shell effective interactions we have previously developed for the p-sd model space (WBT and WBP [3,4] and WBN [5]) and the sd-pf model space (WBMB) remain among the best available [6]. All of these are essential for the interpretation of radioactive beam experiments at the NSCL, and these experiments will indicate how the wave functions and interactions can be improved.

A microscopic model has been recently used [7] in order to study the first order CP effects on C2 form factor of p-shell nuclei. Those calculations depend on the realistic tow-body effective interaction (M3Y) as a residual interaction to generate the core-polarization matrix elements that be added to the model-space matrix elements. The results are quite successful and describe the data very well in both the transition strength and momentum transfer dependence.

The longitudinal electron scattering form factors in even-even sd-shell nuclei (^{18}O, ^{20}Ne, ^{24}Mg, and ^{28}Si) has been studied [8] by taking into account higher energy configurations outside the sd-shell model space which are called core-polarization effects. The two-body Wildenthal interaction is used for the sd-shell model space. Higher configurations are taken into account through a microscopic theory, which allows particle-hole excitation from the 1s and 1p shells core-orbits and also from the 2s1d-shell orbits to the higher allowed orbits with excitations up to $6\hbar\omega$. The two-body Michigan three Yukawas (M3Y) interactions are used for the core-polarization (CP) matrix elements. The effect of core-polarization effect is found essential for the transition strengths and the q-dependent form factors, and improves the agreement with the experimental data remarkably well with no adjustable parameters. Inelastic electron scattering form factors in some odd-A sd-shell nuclei (^{17}O, ^{27}Al and ^{39}K) have been [9] calculated taking into account higher energy configurations outside sd-shell model space, which are called core-polarization (CP) effects.

The aim of the present work is to calculate the electron scattering form factor in some sd-shell nuclei (^{18}O,^{20}Ne and ^{24}M) using OXBASH code for Windows [10]. The model space in this work is extended to include the *pf*-shell orbits ($2p_{3/2}, 2p_{1/2}, 1f_{7/2}$ and $1f_{5/2}$), this model space is usually called *sdpf*-model space. The package of program called "SHELL" were used to generate the One Body Density Matrix Element (OBDME), and the package of program called Dens is used to calculate the electron scattering form factor with spherical Harmonic Oscillator (HO) and the Skyrme Hartree–Fock (HF) radial wave function. Nuclei studied in this research are ^{18}O ($0^+1 \rightarrow 4^+1$) with energy 3.55 MeV, ^{20}Ne ($0^+0 \rightarrow 2^+0$) with energy 1.63 MeV, and ^{24}Mg ($0^+0 \rightarrow 2^+0$) with energy 1.37 MeV.

2. THEORY

Since the implementation of the Skyrme interaction [11] by Vautherin and Brink , this model has proven remarkably useful and successful for nuclear HF calculations. It appears to incorporate the essential physics in terms of a minimal set of parameters, e.g., an *s*- and *p*-wave expansion of an effective nucleon-nucleon interaction together with a density-dependent part which accounts for the truncation of the shell-model space to a closed-shell configuration as well as for three-body interactions. Since the interaction is phenomenological, the parameters need to be determined from experimental data. Most of the parameters of the Skyrme interactions available were obtained by the fitting of HF results to experimental data on bulk properties of a few stable closed shell nuclei. the Skyrme parameters such as SKX, were obtained by the fitting of HF results to the experimental data on the bulk properties of nuclei ranging from the ß-stable nuclei to those near the proton and/or neutron drip lines.

The sd-pf Hamiltonian depends upon four types of TBME [12]:

$\langle sd, sd|V|sd, sd\rangle$ Preedom- Wildenthal (PW) interaction

$\langle pf, pf|V|pf, pf\rangle$ the Van Hees-Glaudemans (VHG) interaction

$\langle sd, pf|V|sd, pf\rangle$ Millener-Kurath (MK) interaction

$\langle sd, sd|V|pf, pf\rangle$

All nuclear structure information is contained in the longitudinal form factor $F_L(q)$, representing the scattering from the nuclear charge density, and the transverse form factor $F_T(q)$, representing the scattering from the nuclear current density. These form factors are given by the well-known multiple decomposition[13]:

$$F_J^2(q)=\frac{4\pi}{Z^2}\frac{1}{(2J_i+1)}\sum_{J\geq 0}\left|\left\langle J_f\left\|\hat{T}_J^L(q)\right\|J_i\right\rangle\times\right|^2\left|F_{c.m}(q)\right|^2\times\left|F_{f.s}(q)\right|^2 \quad (1)$$

The nucleon finite size (fs) form factor is $F_{fs}(q)=\exp(-o.43q^2/4)$ and $F_{cm}(q) = \exp(q^2b^2/4a)$ is the correction for the lack of translation invariance in the shell model.

3. RESULT AND DISCUSSION

In the present work, the electron scattering form factor with core-polarization effects are included through microscopic theory to discuss $J^{+}T = 2^{+}0$ and $4^{+}1$ states for the light sd-shell nuclei ^{18}O, ^{20}N, and ^{24}Mg. Core-polarization effects are taken into account through the first-order perturbation theory, which allows particle-hole and two particles-two holes excitation respectively, from the 1s and 1p shell core orbits to the higher allowed orbits with $2\hbar\omega$ excitation. The one-body density matrix elements (OBDM) values for sd-shell nuclei under consideration in the present work are taken from ref. [15]. The many-particle matrix element that includes both the model space and the core-polarization effects are calculated according to equation (3). Finally, the nuclear form factor can be obtained from equations (1). The ^{18}O nucleus has been the subject of extensive theoretical and experimental studied. They have been received much attention in last decade. The ^{18}O system contains two neutrons in addition to ^{16}O core distribution in sdpf-shell. The electron excites the nucleus from the ground state ($J_iT_i= 0^{+}1$) to the state ($J_fT_f =4^{+}1$) with excitation energy of 3.55 MeV. The single-particle radial wave functions are those of HO potential with size parameter $b_{rms}=1.879\pm0.023$ fm [16]. Figure (1) shows the relation between the longitudinal C4 form factor as a function of momentum transfers, where the dashed curve represents the results of the form factor with sdpf wave function with Core-polarization effects. The upper panel (a) represents the form factor results that calculated with the HO potential for the radial part of the single particle matrix elements, while the lower panel (b) represents those of the Skyrme-Hartree Fock (Skx) interaction. The experimental data are taken from Ref. [17]. The results are closer to the experimental data. The form factors at the low momentum transfer (0.8 -1.5) fm^{-1} with the HO potential give a good agreement with the experimental data, comparing with Skx potential.

From Figure (1-b), one can see that the theoretical results with Skx interaction are in excellent agreement with experimental data in the momentum transfer range between (1.5-2.2) fm^{-1}. The calculated B(C2) values with the inclusion of CP effects is (2.34 × 10^2) e^2 fm^4, in comparison with the measured value (9.04± 0.9 × 10^2 e^2.fm^4 [18]).

^{20}Ne is consider as the ^{16}O core and four nucleons outside the core distribution over $2s_{1/2}$,$1d_{5/2}$,$1d_{3/2}$,$2p_{3/2}$,$2p_{1/2}$,$1f_{7/2}$ and $1f_{5/2}$ shell space. The nucleus is excited from the ground state ($0^{+}0$) by the incident electron to the state ($J_fT_f= 2^{+}$ 0) with excitation energy of 1.63 MeV. The size parameter of the harmonic oscillator (HO) is equal to b_{rms} = 1.869 [15]. In Figure (2), the calculated results of the sdpf-shell model space

The many body reduced matrix elements of the electron scattering operator $\hat{T}_\Lambda^\mu$ consist of two parts, one is for the "Model space" matrix elements, and the other is for the "Core-polarization" matrix elements [14]

$$\left\langle f\left\|\hat{T}_J^\eta(\tau_z,q)\right\|i\right\rangle=\left\langle f\left\|\hat{T}_\Lambda^\eta(\tau_z,q)\right\|i\right\rangle_{MS}+\left\langle f\left\|\hat{T}_\Lambda^\eta(\tau_z,q)\right\|i\right\rangle_{CP} \quad (3)$$

The model space (MS) matrix elements are expressed as the sum of the product of the one-body density matrix elements (OBDM) times the single-particle matrix elements, which is given by:

$$\left\langle J_f\left\|\hat{T}_J^\mu(\tau_z,q)\right\|J_i\right\rangle_{ms}=e(t_z)\int_0^\infty dr\ r^2 j_J(qr)\rho_{J_{t_z}}^{ms}(i,f,r)$$

(4) (4)

Where $\rho_{J_{t_z}}^{ms}(i,f,r)$ is the charge density of model space which is given as:

$$\rho_{J_{t_z}}^{ms}(i,f,r)=\sum_{a,b}OBDM^{J_{t_z}}(i,f,a,b)\left\langle j_a\|Y_J\|j_b\right\rangle R_{n\,l}(r)R_{n'l'}(r) \quad (5)$$

and the core-polarization matrix elements is given as:

$$\left\langle f\left\|\hat{T}_\Lambda^\eta(\tau_z,q)\right\|i\right\rangle_{cp}=e(t_z)\int_0^\infty dr\ r^2 j_J(qr)\rho_{J_{t_z}}^{cp}(i,f,r) \quad (6)$$

where $\rho_{J_{t_z}}^{cp}(i,f,r)$ is the core-polarization transition density which is depends upon the model which is used to calculate the core-polarization effect.

Volume 1 No. 3, September 2011 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

(as the dashed curve) with including the CP effects are compared with experimental data [19]. A good fit the 20Ne data is obtainable with the HO radial wave function in the calculated second diffraction minimum at the high momentum transfer region q ≥ 1.5 fm-1.

The ground state of 24Mg is of 0+0 and can be described by a four proton and four hole in the sdpf orbits outside the 16O inert core. The form factor for the C2 transition to the 0+2 state at 1.37 MeV, is displayed in figure 3, calculated with sdpf-shell model wave functions with Core-polarization effect. The upper panel (a) represents the calculation with the HO potential for the single particle state with size parameter brms=1.813fm

[15]. The lower panel represents the calculations with the Skx interaction with Parameters (α=0.5 and χ=0.73). When the form factor is calculated with HO potential , as shown in the upper panel of figure 3, the results are an excellent agreement with the data from Ref. [20]for the first maximum for the region between (0.6 – 1.7)fm-1, and overestimate the data beyond that. At the lower panel of figure 3, we notice that the theoretical results gives a good agreement for the second diffraction minimum for the momentum transfer q ≥ 1.7 fm-1. This lead to that the Skx interaction is successful to described the experimental data at the high momentum transfer.

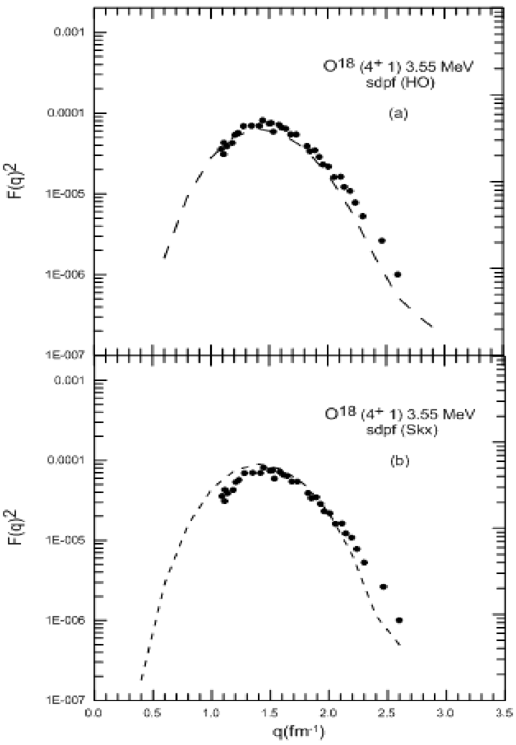

Figure 1. The isovector electron scattering form factors for the $4^{+}1$ (3.55 MeV) state in ^{18}O. The solid curve represent the calculation with sdpf model space. The upper panel represents the form factors that calculated with HO potential for radial part of the single-particle matrix elements, while the lower panel represents those of the Skx interaction. The data are taken from Ref. [20]

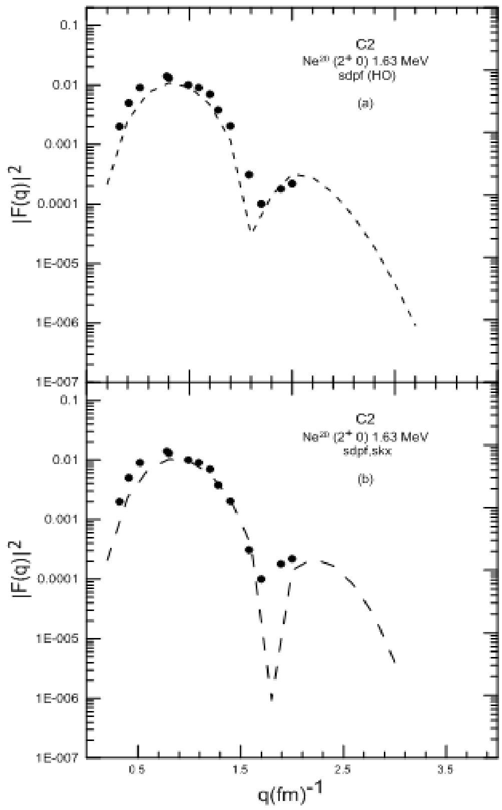

Figure 2. The isoscalar electron scattering form factors for the $2^{+}0$ (1.63 MeV) state in ^{20}Ne. The dashed curve represent the calculation with sdpf-model space. The upper panel represents the form factors that calculated with HO potential for radial part of the single-particle matrix elements, while the lower panel represents those of the Skx interaction. The data are taken from Ref. [19]

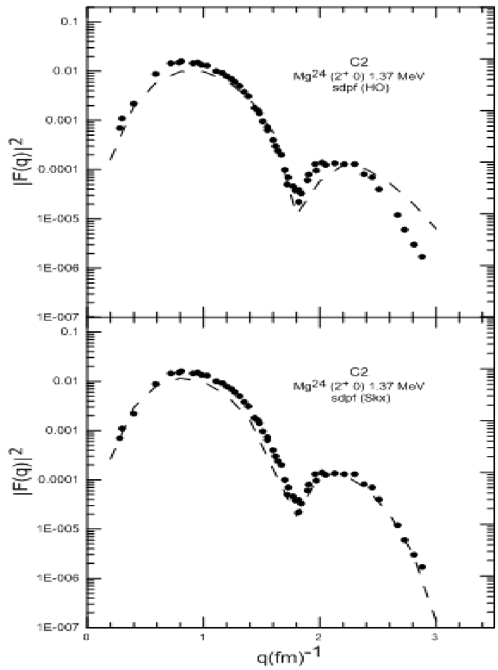

Figure 3. The isoscalar electron scattering form factors for the 2+0 (1.37 MeV) state in 24Mg. The dashed curve

represent the calculation with sdpf-model space. The upper panel represents the form factors that calculated with HO potential for radial part of the single-particle matrix elements, while the lower panel represents those of the Skx interaction. The data are taken from Ref. [20]

ACKNOWLEDGMENT

My express thank to Professor B A Brown of National Superconducting Cyclotron Laboratory, Michigan State University for providing me the computer code OXBASH.

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