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Study of Nuclear Structure of ^{18}F Isotope by using PW and CWH Interactions

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Abstract

In this study, the energy levels of the 18F and electrical transitions B(E2) were calculated by applying the shell model where the calculations were carried out in the SD model space and using the OXBASH code. The theoretical results were compared with the experimental.

Keywords: Nuclear shell model, Energy levels, Light nuclei, OXBASH code, sd-shell, PW and CWH interactions

1. Introduction

Nuclear physics studies the behavior of nuclei in natural conditions and excited states as well as reactions between them. It also focuses on understanding the complex structures of the nucleus and the simpler structures of nucleons (neutrons N and protons Z), which have the same mass and which are the components of the nucleus, nucleus is a group of neutrons N and protons Z is confined to region of 10 fm or less (Bertulani, 2002). One of the main objectives of nuclear physics is to obtain a better understanding of the inner structure of the atomic nucleus and contain protons and neutrons that interact strongly with one another. First It has been established to describe the structure of the nuclei and has proven to be very successful in describing the nuclei (Yang, 2013). The basic assumption in the shell model is that each nucleus moves independently in an average voltage and is capable of predicting the magic numbers as opposed to the atomic shell model. The starting point for any theoretical description of the nucleus is Schrödinger equation. The effective interaction of neoclon-neoclon The importance of the shell model lies in its ability to give approximate or precise levels of energy in which nuclei exist with different values of orbital angular momentum (Dalal, 2004).

2. Theoretical Part

Many methods have been used to calculate nucleic energy levels within high-resolution digital levels and to provide a wave function to calculate other applicable observations. The shell model is one of the most effective methods used for this purpose (Brown, 2005). The basic data in the calculations of the shell model is a set of single particle energies (SPES) and the interaction between two particles of equivalence neocons (TBME). This group is called the active interaction or the Hamilton model space. (McGrory, 1980) With a free neoclone-neoclone reaction and the matrix elements as variables to be adjusted to conform to experimental spectral results (Fiase, 1988) Neoclons move in a limited number of orbits and Hamilton is given equivalence neutrons by (Dean, 2004),

$$H=E_0+\sum_i \varepsilon_i\ a_i^\dagger a_j+\frac{1}{2}\ \sum_{ijkl}\langle ij|V|kl\rangle\ a_i^\dagger a_j^\dagger a_l\ a_k \quad (1)$$

Where the energy of the inert heart is the energies of individual particles of valence circuits $\langle ij|V|kl\rangle$ are the elements of the double-body matrix (TBME) for the effective interaction between neoclone-neoclon of the orptals (i,j,k,l), $a_i^\dagger a_j^\dagger$ are operator of creation and $a_l\ a_k$ are operator of courtyard.

The intrinsic values obtained from matrix H are also used to obtain other matrix elements for important physical effects such as magnetic and electric torque, transducibility probability, beta decay matrix elements, and neoclonon-neoclonin transfer potentials.

3. Oxbash Code

Is a powerful computer system to calculate the energy levels of light and medium nuclei when used. We can measure the energy levels in the kernel and compare them with the experimental program. OXBASH includes a set of computational code based on the ability to measure energy levels by forming ground matrices with dimensions up to 2,000,000 and $J\,T$ Matrix With a dimension of up to 100,000 in order to use this program you must define the model space and interaction. After the selection of space are considered equivalence neutrons. This system organizes a set of possible ground conditions and then makes the $J\,T$ matrix based on a linear component of ground conditions that gives appropriate values of T, J. Finally, after selecting the desired interaction, Hamilton constructs the problem and executes the calculations. The program package, called SHELL, is used to create OBDME components. The software package called LPE is used to calculate wave function and power levels (Mohammadi, 2015).

$$H = \sum_{a} \epsilon_a \, \vec{n}_a + \sum_{\substack{a \le b \\ c \le d}} \sum_{JT} V_{JT}(ab;cd)\, \hat{T}_{JT}(ab;cd) \tag{2}$$

The appropriate expression for Hamilton is the shell model given as a sum of single and double-particle effects (Mohammadi, 2014),

$$\hat{T}_{JT}(ab;cd) = \sum_{M\,T_z} A^{+}_{JMTT_z}(ab)\, A_{JMTT_z}(cd) \tag{3}$$

where ϵ_a represents a single serious energy $\vec{n}_a$ number of impressive orbit a with quantum number (n_a, l_a, j_a). $V_{JT}(ab;cd)$ elements of the matrix for the dual particle and (a,b) and (c,d) transition is a measure of the numerical density of the two-particle pairs for each pair Alnyuklon coupled with a number of quantitative twines $J\,M$ (Honma, 2002) one of the methods to study the installation of the kernel and interactions NN called the installation of a specimen crust by which we deal with all degrees of freedom in this model. The protons and neutrons move in all the orbits of the serious individual and specific three constraints (twines, the angular momentum and parity) (Dean, 2004; Brown, 2006). As is well-known interaction between the two protons or neutrons or proton and neutron is the same is almost therefore been provided twines T as the number of how much new .dalh wave grave single proton and neutron are expressed using twines $t = 1/2$ to distinguish between the types of nucleons can distinguish the nuclear cases, the nucleus of protons Z and neutrons N (A = N + Z) specific values of numbers quantity T, T_z (Lawson, 1980),

$$T_z = \frac{N-Z}{2}, \quad \frac{N-Z}{2} \le T \le \frac{A}{2} \tag{4}$$

We can also calculate the potential angular momentum states that arise when there is more than one nucleus outside the closed heart (Lawson, 1980).

* If there are two similar neoclons and they are in the same orbit of the single block the angular momentum J is calculated :

$$J = 0, 2, 4, \dots, 2j-1 \tag{5}$$

* If similar neoclonin is found at two different levels, one at the level J_1 and the other at J_2 where J_1 where $J_2 \neq J_1$ angular momentum is :

$$J = j_1 + j_2\,, j_1 + j_2 - 1\,, \dots, |j_1 - j_2| \tag{6}$$

* In general for similar neocons, if all are in the same orbit, the highest value of the angular momentum of J_M is (Lawson, 1980):

$$J_M = n\left\{j - \frac{(n-1)}{2}\right\} \tag{7}$$

The purpose of this work is to study the effects of this Hamilton in the nuclear structure. Hamilton's accuracy is explained in all energy levels (Hamilton's intrinsic values) and the probability of transition depends mainly on the wave function functions of this accuracy. The PW, CWH interaction is used to calculate energy levels and the probability of electric quartile transitions Experimental data for the ^{18}F analog The calculations were performed using the OXBASH program in the space of the SD model of the ^{18}F nucleus containing one proton and one neutron outside the closed heart ^{16}O that occupy the model space $1d_{5/2},\ 2S_{1/2},\ 1d_{3/2}$ according to the Pauli principle.When a nucleus in the SD shell is described by model space, all nucleons are taken into account in space to describe levels of nuclear energy. Model space is a powerful tool for studying the levels and nuclear structure of any nucleus (Abed Dagher, 2016).

The shell model is based on the following assumptions (Brown, 2006):

(1) Fill three sealed closed inner nucleons $1S_{1/2}$, $1P_{3/2}$, $1P_{1/2}$ to form an inert nucleus with a sequence of $J = 0$ and the theoretical torsion $T = 0$ External nuclei (external) are moving independently in the available orbits $1d_{5/2}$, $2S_{1/2}$, $1d_{3/2}$ for the sphere of the central voltages.

(2) The strong interaction of the ureptal limb separates each level (j) to $j = l + 1/2$ and $j = l - 1/2$ where $j = l + S$ is the single mass level j_1, j_2.

(3) Interaction can be expressed as a total interaction of two particles (Brussaad, 1977),

$$H = H_{core} + H_{12} \tag{8}$$

Where H_{core} represents Hamilton's heart-express interaction of particles in the heart, H_{12} represents Hamilton's two interacting particles which describe the behavior of the two particles outside the heart. H_{12} can be expressed in the following formula (Brussaad, 1977),

$$H_{12} = H_{12}^{(0)} + H_{12}^{(1)} \tag{9}$$

Where $H_{12}^{(0)}$ Hamilton is known as the single particle $H_{12}^{(1)}$ Hamilton defines the residual reaction.

4. Calculations and Results

Can study and calculate the energy levels based on the shell model depending on the quantum study system and analyze the ^{18}F gentle energy levels in the model space of the regular arrangements $1d_{5/2}$, $2S_{1/2}$, $1d_{3/2}$ top core ^{16}O core There are different effective interactions Use the PW, ^{18}F The objective of this study is to calculate the energy levels and probability of the B(E2) transitions using the harmonic oscillator (HO, b), $b < o$ and use the OXBASH program which has the ability to calculate the equations by executing certain orders after selecting both the effective interaction and the model space The counterpart specified in the study. Based on the values of the single gravity energies and the model space of the studied nuclei as well as the values of the matrix elements using both the pw and CWH interactions, we obtain the energy level values of the ground state, which were compared with the experimental values available to us.

4.1 Energy Levels

From Table 1 and Table 2 and Figure 1, we can compare the theoretical values of the energy levels relative to the ground state of the Fourier nucleus ^{18}F using PW and CWH with the practical values available and according to the total angular momentum values and symmetry. The results were discussed according to angular momentum values, The resulting values are consistent with the available process values. By studying the energy levels of ^{18}F nuclei by applying the nuclear shell model and using the PW voltage, it shows the following :

1. The total angular momentum and the ground condition of level 1^+_1 were obtained when compared with the practical values available to us.
2. We found a good approximation of the calculated energies of (0.779, 0.830, 3.084, 3.610, 3.736, 6.224, 8.747 MeV) with the values of the practical energies available to us respectively which have the same angular momentum values (3^+_1 , 5^+_1 , 2^+_1, 1^+_2 , 3^+_2 , 1^+_3 , 3^+_3), We also found a good correlation of the calculated energy value of (6.097 MeV) to the angular momentum 4^+_1 with the practical value MeV (6.096 MeV) but with different symmetry.
3. We expect the total angular momentum of the practical energy (7.247 MeV) which is practically uncertain by the total angular momentum and the 2^+ symmetry.
4. The practical energy value (10.580 MeV) and the non-specific angular momentum. In practice, we expect it to be a total angular momentum and a similarity of 2^+ after comparing it with the practical values.
5. We found a calculated energy value theoretically that did not meet any value from the available operational values (9.498 MeV) and with a total angular momentum of 1^+_4 and we found two new energies (15.398, 14.121 MeV) and an angular momentum and similarity (1^+_5 , 3^+_4) The highest theoretical energy value was (15.398 MeV), while the highest energy value was (10.580 MeV).

Table 1. Compared experimental results with the theoretical calculations PW interaction for ^{18}F

Experimental values		Theoretical values	
J^{π}	E (MeV)	E (MeV)	J^{π}
1^+	0.000	0.000	1_1^+
3^+	0.937	0.779	3_1^+
5^+	1.121	0.830	5_1^+
2^+	3.061	3.084	2_1^+
1^+	3.724	3.610	1_2^+
3^+	3.358	3.736	3_2^+
4^-	6.096	6.097	4_1^+
1^+	6.262	6.224	1_3^+
(1^+)	7.247	7.255	2_2^+
$3,4^-$	9.207	8.747	3_3^+
--------	--------	9.498	1_4^+
--------	10.580	11.147	2_3^+
--------	--------	14.121	3_4^+
--------	--------	15.398	1_5^+

Table 1 and Figure 1 shows the comparison of the theoretical values of the energy levels relative to the ground state of the ^{18}F nucleus using the PW voltage with the available experimental values (Tilley, 1995).

Table 2 and Figure 1 shows the comparison between the theoretical values of the energy levels relative to the ground state of the ^{18}F nucleus using the CWH voltage with the available practical values (Tilley, 1995) for the total angular momentum values and symmetry.

By studying the energy levels of the ^{18}F nuclei and by applying the CWH nuclear shell model, :

1- The total angular momentum and the ground state of level 1^+_1 were obtained when compared with the practical values available to us.

2- We obtained a good approximation of the theoretical energy values of (0.203, 0.499, 3.429, 3.462, 3.847, 6.435, 6.562, 8.679 MeV) with the values of the practical energies available to us respectively which have the same total angular momentum values and symmetry (5^+_1 , 3^+_1 , 2^+_1 , 3^+_2 , 1^+_2 , 4^+_1 , 2^+_2 , 3^+_3).

3. We expect the total angular momentum and the similarity of practical energy (6.108 MeV) which is practically uncertain with total angular momentum and 1^+ after comparing them with the practical values.

4. We predict the determination of the total angular momentum and the similarity of the undefined (10.580 MeV) to the angular momentum with a total angular momentum of 2^+.

5. The calculated theoretical energy value, which was not matched by any practical value, was obtained from the available values of (9.459 MeV) and with a total momentum of 1^+_4.

6. We obtained two new theoretical energy values of (16.119, 14,739 MeV) above the practical energy value. The highest theoretical energy value was (16.119 MeV) while the highest value of the practical energy was (10.580 MeV).

Table 2 Comparison of the theoretical values of the energy levels relative to the ground state of the ^{18}F nucleus using CWH voltage with the available operational values (Tilley, 1995) and according to the total angular momentum values and symmetry

Table 2. Compared experimental results with the theoretical calculations CWH interaction for ^{18}F

Experimental values		Theoretical values	
J^{π}	E (MeV)	E (MeV)	J^{π}
1^+	0.000	0.000	1_1^+
5^+	1.121	0.203	5_1^+
3^+	0.937	0.499	3_1^+
2^+	3.061	3.429	2_1^+
3^+	3.358	3.462	3_2^+
1^+	3.724	3.847	1_2^+
(1^+)	6.108	6.088	1_3^+
4^+	6.777	6.435	4_1^+
2^+	6.385	6.562	2_2^+
$3^+,4^+$	7.685	8.679	3_3^+
--------	--------	9.459	1_4^+
--------	10.580	11.216	2_3^+
--------	--------	14.739	3_4^+
--------	--------	16.119	1_5^+

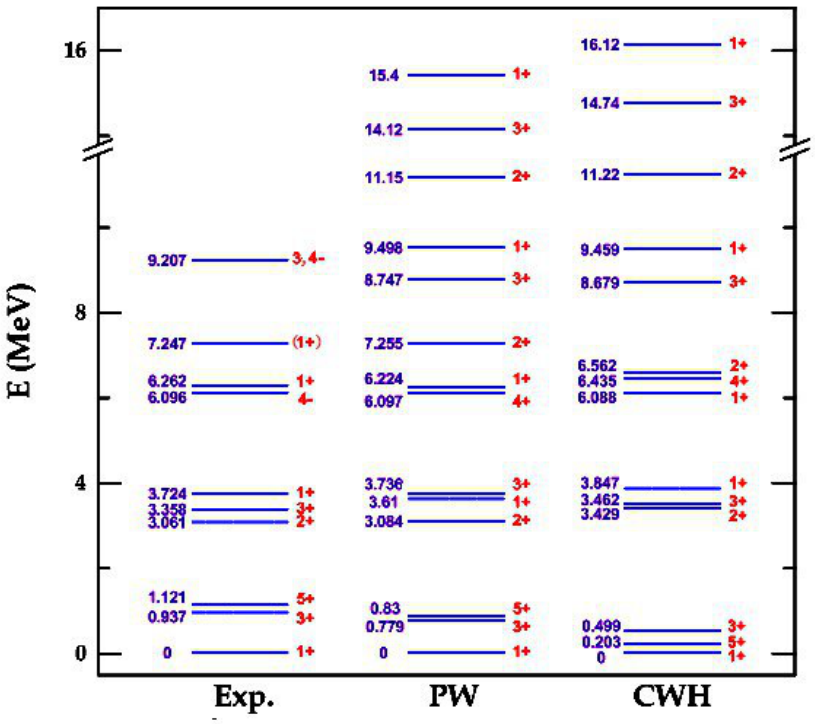

Figure 1. Comparison of the theoretical values of the energy levels relative to the ground state of the ^{18}F nuclei using the pw and CWH voltage with the available operational values (Tilley, 1995) and according to the total angular momentum values and symmetry

4.2 Quadrupole Transition

The probability of electric quadrature transmission B(E2) for the ^{18}F coupling in the shell model and using the Oxbash program in the sd-shell was obtained by using the CWH and PW interactions with the harmonic oscillator (HO). The electrical transitions B(E2) The theoretical values are consistent with the practical values available to us at the first transfer (Tilley, 1995) at the charge ep = 0.255e = en for the reaction PW and at the charge en = ep = 0.323e relative to the CWH interaction as shown in Table 3 and 4.

Table 3. Compare the values of B(E2) to the corresponding ^{18}F obtained for PW interaction

$J_i \rightarrow J_f$	PW results ep = en = 0.255e	Experimental $B(E2)$, e^2 fm^4
$3_1^+ \rightarrow 1_1^+$	16.09	16.095 6
$5_1^+ \rightarrow 3_1^+$	20.12	--------
$2_1^+ \rightarrow 1_1^+$	14.69	--------
$2_1^+ \rightarrow 3_1^+$	12.59	--------
$4_1^+ \rightarrow 3_1^+$	2.722	--------
$4_1^+ \rightarrow 5_1^+$	3.562	--------
$4_1^+ \rightarrow 2_1^+$	14.99	--------
$1_2^+ \rightarrow 1_1^+$	2.160	--------
$1_2^+ \rightarrow 3_1^+$	47.67	--------
$1_2^+ \rightarrow 2_1^+$	0.5726	--------
$3_2^+ \rightarrow 1_1^+$	0.4873	1.91475 25
$3_2^+ \rightarrow 3_1^+$	1.796	--------
$3_2^+ \rightarrow 5_1^+$	0.0331	--------
$3_2^+ \rightarrow 1_2^+$	7.724	58.275 8
$2_2^+ \rightarrow 1_1^+$	0.002721	--------
$2_2^+ \rightarrow 3_1^+$	0.9091	-------
$2_2^+ \rightarrow 2_1^+$	0.5072	--------
$2_2^+ \rightarrow 4_1^+$	0.1676	--------
$2_2^+ \rightarrow 1_2^+$	2.326	--------
$2_2^+ \rightarrow 3_2^+$	7.175	--------
$1_3^+ \rightarrow 1_1^+$	19.21	--------
$1_3^+ \rightarrow 3_1^+$	0.01172	--------
$1_3^+ \rightarrow 2_1^+$	21.51	--------
$1_3^+ \rightarrow 1_2^+$	1.581	--------
$1_3^+ \rightarrow 3_2^+$	0.002927	--------
$3_3^+ \rightarrow 1_1^+$	0.2512	0.41625 11
$3_3^+ \rightarrow 3_1^+$	0.09548	--------
$3_3^+ \rightarrow 5_1^+$	0.1295	--------
$3_3^+ \rightarrow 2_1^+$	4.046	--------
$3_3^+ \rightarrow 4_1^+$	2.2718	--------
$3_3^+ \rightarrow 1_2^+$	0.06698	--------
$3_3^+ \rightarrow 3_2^+$	2.171	--------
$3_3^+ \rightarrow 2_2^+$	3.244	--------
$3_3^+ \rightarrow 1_3^+$	11.83	--------

$2_3^+ \rightarrow 2_1^+$	0.03186	--------
$2_3^+ \rightarrow 4_1^+$	4.243	--------
$2_3^+ \rightarrow 1_2^+$	3.278	--------
$2_3^+ \rightarrow 3_2^+$	1.075	--------
$2_3^+ \rightarrow 2_2^+$	0.06698	--------
$1_4^+ \rightarrow 1_1^+$	1.390	--------
$1_4^+ \rightarrow 2_1^+$	6.159	--------
$1_4^+ \rightarrow 3_2^+$	0.03537	--------
$1_4^+ \rightarrow 2_2^+$	12.06	--------
$1_4^+ \rightarrow 3_3^+$	1.706	--------
$1_4^+ \rightarrow 2_3^+$	1.786	--------
$3_4^+ \rightarrow 1_1^+$	0.01917	0.2775 3
$3_4^+ \rightarrow 5_1^+$	0.08012	3.6075 11
$3_4^+ \rightarrow 3_3^+$	3.522	--------
$3_4^+ \rightarrow 2_3^+$	11.03	--------

Table 4. Compare the values of B(E2) to the corresponding ^{18}F obtained for CWH interaction

$J_i \rightarrow J_f$	CWH results ep = en = 0.323e	Experimental $B(E2)$, e^2 fm^4
$3_1^+ \rightarrow 1_1^+$	16.04	16.095 6
$3_1^+ \rightarrow 5_1^+$	29.96	--------
$2_1^+ \rightarrow 1_1^+$	14.56	--------
$2_1^+ \rightarrow 3_1^+$	13.94	--------
$4_1^+ \rightarrow 5_1^+$	3.562	--------
$4_1^+ \rightarrow 3_1^+$	2.836	--------
$4_1^+ \rightarrow 2_1^+$	12.59	--------
$3_2^+ \rightarrow 1_1^+$	0.01527	1.91475 25
$3_2^+ \rightarrow 5_1^+$	4.409	--------
$3_2^+ \rightarrow 3_1^+$	2.851	--------
$3_2^+ \rightarrow 2_1^+$	6.823	--------
$1_2^+ \rightarrow 3_1^+$	10.07	--------
$1_2^+ \rightarrow 2_1^+$	0.4798	--------
$1_2^+ \rightarrow 3_2^+$	23.32	--------
$2_2^+ \rightarrow 1_1^+$	0.8744	--------
$2_2^+ \rightarrow 3_1^+$	0.06258	--------
$2_2^+ \rightarrow 2_1^+$	0.00003731	--------
$2_2^+ \rightarrow 4_1^+$	0.6748	--------
$2_2^+ \rightarrow 3_2^+$	6.931	--------
$2_2^+ \rightarrow 1_2^+$	0.3996	--------
$1_3^+ \rightarrow 1_1^+$	10.80	--------
$1_3^+ \rightarrow 3_1^+$	0.1984	--------
$1_3^+ \rightarrow 2_1^+$	17.35	--------
$1_3^+ \rightarrow 3_2^+$	1.386	--------

$1_3^+ \rightarrow 1_2^+$	1.314	--------	
$3_3^+ \rightarrow 1_1^+$	0.07038	0.41625	11
$3_3^+ \rightarrow 5_1^+$	0.4038	--------	
$3_3^+ \rightarrow 3_1^+$	0.04792	--------	
$3_3^+ \rightarrow 2_1^+$	4.425	--------	
$3_3^+ \rightarrow 4_1^+$	1.633	--------	
$3_3^+ \rightarrow 3_2^+$	3.186	--------	
$2_3^+ \rightarrow 1_2^+$	1.395	--------	
$3_3^+ \rightarrow 2_2^+$	0.005375	--------	
$3_3^+ \rightarrow 1_3^+$	8.470	--------	
$2_3^+ \rightarrow 2_1^+$	0.04643	--------	
$2_3^+ \rightarrow 4_1^+$	8.045	--------	
$2_3^+ \rightarrow 3_2^+$	1.204	--------	
$2_3^+ \rightarrow 1_2^+$	3.665	--------	
$2_3^+ \rightarrow 2_2^+$	3.145	--------	
$2_3^+ \rightarrow 1_3^+$	0.8584	--------	
$1_4^+ \rightarrow 1_1^+$	1.826	--------	
$1_4^+ \rightarrow 2_1^+$	6.729	--------	
$1_4^+ \rightarrow 3_2^+$	0.005567	--------	
$1_4^+ \rightarrow 2_2^+$	13.13	--------	
$1_4^+ \rightarrow 3_2^+$	3.522	--------	
$3_4^+ \rightarrow 1_1^+$	0.04583	0.2775	3
$3_4^+ \rightarrow 5_1^+$	0.05015	3.6075	11
$3_4^+ \rightarrow 1_2^+$	0.1821	--------	
$3_4^+ \rightarrow 2_3^+$	9.315	--------	

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