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Study of Nuclear Structure of $^{42-43}$Ti isotopes using F7MBZ & F742 interactions

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ABSTRACT

In this work, The energy levels and lowered electric quadruple transition probability B(E2) were calculated with the use of the OXBASH code in the F7shell and the F7MBZ& F742 effective interaction for the $^{42-43}$Ti isotopes. All nucleon combinations in the $1f_{7/2}$ orbits are included in the model space. Additionally, the shell model does a good in describing the invading states' energies. Computations have been done using effective interactions F7MBZ and F742 in full f7 space, As well as the shell model , Lowlying states and binding energies computed and it was found that the calculated rates of electric quadrupole transitions between the isotopes $^{42-43}$Ti were consistent with the existing experimental published data.

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دراسة التركيب النووي لنظائر $^{٤٢-٤٣}$Ti باستعمال التفاعلان F7MBZ & F742

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الكلمات المفتاحية:

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الـــخُـــلاصـــة

تحسب هذه الدراسة مستويات الطاقة وإمكانات الانتقال لرباعي القطب الكهربائي المختزل*B(E2)* لنظائر *Ti*$^{٤٢-٤٣}$ باستعمال كود *OXBASH* ضمن قشره *F7* والتفاعلات الفعالة. والترتيب المتضمن في أنموذج القشرة المداري $1f_{7/2}$, يتم وصف طاقة الحالات المتداخلة جيدًا بواسطة أنموذج القشرة. الحسابات يتم أنجازها مع التفاعلات المؤثرة (*F7MBZ & F742*) في قشرة *F7* ، كانت قيم طاقات الحالات الأرضية والمتهيجة المحسوبة واحتمالية الانتقال رباعي القطب الكهربائي في توافق مقبول مع النتائج العملية.

1. INTRODUCTION

One of the requirements for enhancing inquiries into the properties of nuclei is to obtain structures and energies of nuclei. Shell-model is one of the most well-known and effective nuclear models. The structure of nuclei is now easier to understand with the use of nuclear models, which contains the fundamental physical properties of nuclei. This model is comparable to the atom's electron shell theory. The nuclear features of a nucleus are mostly determined by the value nucleons protons or neutrons located in close-proximity shells with magic numbers (2,8,20,28,50,82, and 126), Just as valance electrons that reside outside of a closed shell can characterize atomic behavior and properties. Magic number nuclei are extremely stable and have entirely different characteristics [1]. All of these shell-model calculations begin with the formulation of an effective interactions [2]. The goal of this work is to use the shell model and the B (E2) values for the neutron and proton orbits in the $^{42-43}$Ti energy levels. The model of a nuclear shell can make a many predictions keeping close track of data and doing so methodically [3]. With up to 50,000 dimensions in the J-T scheme and 2,000,000 dimensions in the M-scheme, This program's algorithms may calculate shell models [2]. Within the context of the shell model, in the f7-shell region, Nuclear spectroscopy has been well characterized. A variety of model spaces and two-body interactions were used in Brown and colleagues' most notable work [4] .There are two characterizations of the space of Hamiltonian models are equivalent .One approach is called "realistic," and it involves building a shell model space for a specific set of free parameters nucleon-nucleon force. Second, There is the "empirical" approach, Which relies in some way on parameters whose values are derived by requiring agreement between observed level energies and shell-model eigenvalues [5].

2. THEORY

The main contributor to the expansion n of Brown has used the shell-model code OXBASH . there are a number of Unix distributions, Recently, Other speedier shell-model codes have been created, Including the ANTOINE and MSHELL m-scheme codes, as well as the NATHAN J-scheme code . However , one of the most adaptable codes now in use is OXBASH. Up to roughly 250 m-states and 30 j-states have been added to it. The speedier codes indicated above, As far as we are aware, Have only been set up, And work is currently being done to enhance calculations that can be performed in a wide variety of model spaces with hundreds of interactions using this OXBASH righ. With OXBASH, You can figure out energy levels, Cluster overlaps, Transition densities, Spectroscopic factors for both one and two nucleons [6] . Effective interaction, Often known as model space Hamiltonian, Is the new name for these groups. Two techniques can be used to explain this Hamiltonian model space: The first approach is realistic; it is tailored to a particular shell-model space. According to the existing knowledge of the free nucleon-nucleon force "Empirical" is the second way, And it is based on just one type of evidence [5].

In general, Hamiltonian, Which controls the dynamics of protons and neutrons according to the nuclear shell model, Is expressed in the following [7]

$$H = \sum_i \varepsilon_i n_i + \sum_{ijkl} V_{ijkl}\, a_i{}^{\dagger} a_j{}^{\dagger} a_i\, a_j \qquad (1)$$

Where:

$\boldsymbol{\varepsilon_i}$**:** is single - level energy , $\boldsymbol{i}$: the vicinity of the closed shell with a mass number A = closed core +1 , n_i :the quantity of nuclei present at each level I, V_{ijkl} :Two-Body Matrix Elements(TBME),

$a_i{}^{\dagger}$, $a_j{}^{\dagger}$ are the Creation operators , a_i, a_j are annihilation operators that calculate the permitted angular momentum states using the theorems [7].

First Theorem: Two identical particles can only link their spins to even values of j (j half integer) if they are in the same single particle orbit.

$$J = 0, 2, 4, \dots (2j - 1) \qquad (2)$$

Second Theorem: The values of permissible angular momentum for two particles in the states J_1 and J_2 ($J_1 \neq J_2$) are:

$J = J_1 + J_2 , J_1 + J_2 - 1 , \dots |J_1 - J_2|$ (3)

Three theorem: When nucleons are identical to protons and neutrons in the same single massive orbit where n> 2, where n represents many particles there are outside of the closed shell [8].

$$JM = n\{j - \frac{(n-1)}{2}\} \quad (4)$$

It is possible to define the likelihood of a reduced electric transition as [9]:

$$B(\bar{W}L: Ji \rightarrow Jf) = \frac{< J_f \ \|0(\bar{W}L)\| J_i >^2}{2J_i + 1}$$

Where (j_i and j_f) are the initial and terminal spins, respectively and $0(\bar{W}$L)is the electric multipole operator[10].

3. CALCULATIONS AND DISCUSSION

The computations were done in the F7 model space with the help of the code OXBASH. For ^{42,43}Ti with effective interaction were (F7MBZ & F742) .The core is considered as ^{40} Ca for ^{42}Ti with 2 nucleons outside core and for ^{43}Ti with 3 nucleons outside core . When using a projection technique, Waves have good angular. The construction of isospin T and momentum J. Below the closed Z = N = 20 shell, (1d3/2) made up the(F7MBZ & F742) model space. A harmonic oscillator's potential (HO, b), often known as b >0, was employed. The predicted results for the even and odd A nuclei's states, proton atomic numbers of 22 and neutron numbers 20, 21 are provided in this study. The energy levels and the B (E2) value. When comparing the results of this work with the results of Calculation of Energy Level and B (E2) for $^{44-42}$Ti and $^{44-42}$Sc by Using Shell Model Code OXBASH using effective interactions (f7cdpn, f742pn) a good agreement was found with the available practical results.

3.1 Levels of energy

3.1.1 ٤٢Ti nucleus:

In accordance with the shell model, a closed ^{40}Ca core constitutes the ^{42}Ti nucleus' ground state, the arrangement of the nucleons in the F7-shell is made up of the excited states. In the current study, We employ interaction between (F7MBZ & F742), comparison between theoretical findings to existing experimental findings were conducted [11] For Titanium isotopes using (F7MBZ & F742) interaction is show in the Table1. We noted (F7MBZ & F742) From this table Hamiltonians and experimental data generally agree. When compared against the experimental data that is presented, Both the parity and angular momentum are found to be identical to the ground state of level 0+. Compared to experimental data, the states (2+, 4+, 6+) show good agreement. Through our calculations, the highest value of energy calculated theoretically is (3.4) MeV while the highest value of energy is (7.5) MeV.

Table(1): Excitation energy predicted by (F7MBZ & F742) interactions and observed excitation energies[12] for the ^{42}Ti nucleus are compared.

J^{π}	Theory E (MeV)		Exp. E (MeV)
	F7MBZ	F742	
0^+	0	0	0
2^+	1.509	1.586	1.5546
4^+	2.996	2.817	2.6766
6^+	3.404	3.237	3.043

3.1.2 ^{43}Ti nucleus:

Of the ground state of the ^{43}Ti nucleus, the ^{40}Ca core is closed, while the nucleons in the F7-shell are arranged in an excited state. In this study, we employed (F7MBZ & F742) interaction.The parity and angular momentum consistent with the level of ground state according to the available experimental data. The experimental energy value (1.8577 , 3.0664 , 2.9517) MeV was confirmed for angular momentum ($11/2^-$, $19/2^-$, $15/2^-$), and The experimental energy value(2.0624) MeV was confirmed for angular momentum ($9/2^+$) with negative parity In our calculations, We expect the angular momentum and parity to experimental energies (3.220) MeV is ($7/2_2^-$) when compared with our theoretical values. Based on current calculations, We found ten values of energies (3.409 , 3.844 , 4.129 , 4.622 , 4.816 , 4.878 , 5.141 , 5.429 , 5.478 , 5.817) MeV corresponding to angular momentum ($3/2_1^-$, $13/2_1^-$, $5/2_1^-$, $17/2_1^-$, $5/2_2^-$, $9/2_2^-$, $11/2_2^-$, $7/2_3^-$, $1/2_1^-$, $13/2_2^-$) were higher than the experimental values available until now. The highest value of energy calculated theoretically is (5.817) MeV while the highest value of energy is (3.2) MeV meaning that we have obtained ten new levels above the practical value.

Table (2): A comparison between the theoretical and experimental data that is currently available for the ^{43}Ti nucleus by using the F7MBZ interaction.

J^π	Theory E(MeV) F7MBZ	Exp. E (MeV)	J^π
$7/2_1^-$	0	0	$7/2_1^-$
$9/2_1^-$	1.681	2.0624	$(9/2^+)$
$11/2_1^-$	2.440	1.8577	$(11/2^-)$
$7/2_2^-$	3.248	3.220	-----
$3/2_1^-$	3.409	-----	-----
$19/2_1^-$	3.643	3.0664	$(19/2^-)$
$15/2_1^-$	3.711	2.9517	$(15/2^-)$
$13/2_1^-$	3.844	-----	-----
$5/2_1^-$	4.129	-----	-----
$17/2_1^-$	4.622	-----	-----
$5/2_2^-$	4.816	-----	-----
$9/2_2^-$	4.878	-----	-----
$11/2_2^-$	5.141	-----	-----
$7/2_3^-$	5.429	-----	-----
$1/2_1^-$	5.478	-----	-----
$13/2_2^-$	5.817	-----	-----

The parity and angular momentum are equivalent when compared to the presented experimental data, the ground condition of level. the experimental energy value (1.8577 , 3.0664 , 2.9517) MeV was confirmed for angular momentum ($11/2^-$, $19/2^-$, $15/2^-$) And The experimental energy value(2.0624) MeV was confirmed for angular momentum ($9/2^+$) with negative parity In our calculations, We expect the angular momentum and parity to experimental energies (2.438 , 2.640, 3.220) MeV is ($7/2_2^-$, $3/2_1^-$, $13/2_1^-$) when compared with our theoretical values. Based on current calculations, we found ten values of energies (3.444 , 4.291, 3.937, 4.103, 4.411, 4.391, 4.318, 4.943) MeV corresponding to angular momentum ($5/2_1^-$, $17/2_1^-$, $5/2_2^-$, $9/2_2^-$, $11/2_2^-$, $7/2_3^-$, $1/2_1^-$, $13/2_2^-$) were higher than the experimental values available until now. Through our calculations, The highest value of energy calculated theoretically is (4.943) MeV while the highest value of energy is (3.2) MeV meaning that we have obtained eight new levels above the practical value.

Table (3): A comparison between the theoretical and experimental data that is currently available for the ^{43}Ti nucleus by using the F742 interaction.

J^π	**Theory E (MeV) F742**	**Exp. E (MeV)**	J^π
$7/2_1^-$	0	0	$7/2_1^-$
$9/2_1^-$	1.681	2.0624	$(9/2^+)$
$11/2_1^-$	2.336	1.8577	$(11/2^-)$
$7/2_2^-$	2.791	2.438	-----
$3/2_1^-$	2.889	2.640	-----
$19/2_1^-$	3.638	3.0664	$(19/2^-)$
$15/2_1^-$	3.512	2.9517	$(15/2^-)$
$13/2_1^-$	3.503	3.220	-----
$5/2_1^-$	3.444	-----	-----
$17/2_1^-$	4.291	-----	-----
$5/2_2^-$	3.937	-----	-----
$9/2_2^-$	4.103	-----	-----
$11/2_2^-$	4.411	-----	-----
$7/2_3^-$	4.391	-----	-----
$1/2_1^-$	4.318	-----	-----
$13/2_2^-$	4.943	-----	-----

3.2 B(E2) Calculations :

3.2.1 B(E2) for ^{42}Ti

The lower probability of an electric quadruple transition B (E2) were predicted for ^{42}Ti within the nuclear shell model using (F7MBZ & F742) . This work includes the calculation the transition probability by using the harmonic oscillator potential (HO, b), Where b < 0 for each in-band transition under the assumption of pure E2 transition. The effective charges for the proton (e_p=1.9e) and neutron (e_n=1.9e) have been chosen to account for core polarization effects. The ^{42}Ti in Table 4 was computed using the effective interactions of F7MBZ and F742. On the whole, One of the calculated outcomes are reasonable agreement with the currently accessible experimental data.

Table (4): The B (E2) values for ^{42}Ti's ground-state band. They use e^2fm^4 units, which match the experimental results.

J_i^+	→	J_f^+	Theory B(E2) (e^2 fm^4)		Exp. B(E2) (e^2 fm^4) e_p = 1.9e e_n = 1.9e b =2.235 fm
			F7MBZ	F742	
2	→	0	138.2	138.2	138.752
4	→	2	137.9	137.9	---
6	→	4	62.84	62.48	27.7504

3.2.2 . B(E2) for ^{43}Ti

The lower probability of an electric quadruple transition B (E2) were predicted for ^{43}Ti within the nuclear shell model using (F7MBZ & F742) . This work includes the calculation the transition probability by using the harmonic oscillator potential (HO, b), Where b < 0 for each in-band transition under the assumption of pure E2 transition. The effective charges for the proton (e_p=1.5e) and neutron (e_n=1.5e) have been chosen to account for core polarization effects. The ^{43}Ti in Table 5 was computed using the effective interactions of F7MBZ and F742. On the whole, One of the calculated outcomes are reasonable agreement with the currently accessible experimental data.

Table (5): The B (E2) values for ^{43}Ti's ground-state band. They use e^2fm^4 units, which match the experimental results.

J_i^-	→	J_f^-	Theory B(E2) (e^2 fm^4)		Exp. B(E2) (e^2 fm^4) e_p = 1.5e e_n = 1.5e b=2.171fm
			F7MBZ	F742	
9/2	→	7/2	232.4	218.6	---
7/2	→	9/2	290.5	273.2	---
11/2	→	9/2	202.5	205	---
15/2	→	11/2	104.3	103.9	---
13/2	→	11/2	84.48	87.35	---
11/2	→	7/2	64.59	69.43	---
3/2	→	7/2	55.46	62.43	---
5/2	→	3/2	27.25	23.64	---
7/2	→	3/2	27.73	31.22	---
5/2	→	9/2	9.832	5.949	---
5/2	→	7/2	0.3249	1.336	---

4. CONCLUSIONS

The current investigation reveals that the interaction files employed in this study provide good findings that are consistent with the calculated energy levels and transition probability B (E2) to the actual process values. The level spectra and calculations for the shell model in f7 space were replicated by utilizing the Windows program OXBASH for the nuclei $^{42-43}$Ti, As well as the transition probability B(E2). By comparing these calculations to recently available experimental data on level spectra and transition probabilities using both f7MBZ and f742 effective interactions, Good agreements were obtained. Ultimately the most effective interaction in this study was F742.

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