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Calculation of Energy Levels and Reduced Electric Quadrupole Transition Probability for ^{22}F Isotope Using Oxbash Code

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ABSTRACT

A study on the calculation of energy levels and reduced electric quadrupole transition probability for fluorine-22 isotope using Oxbash Code has been carried out. The shell model and OXBASH was used to calculate the energy levels and probability of quadratic transition B(E2) of the ^{22}F isotope in the SD region through PW, CWH active interactions. A comparison was made between the calculation results and the experimental data. The comparison shows considerable consistency with the experimental results. The total angular momentum of the ground level 4^{+}_{1} was confirmed when comparing with the experimental values. A significant consistency was obtained for the calculated energy values MeV (1.734, 2.387, 2.946) with the available experimental values of the same angular momentum (1^{+}_{1},12+,4^{+}_{2}). It can be concluded that the reduced transition probabilities B(E2) can be calculated using the PW, CWH reactions and OXBASH code.

INTRODUCTION

Nuclear physics studies the behavior of nuclei in the natural conditions and agitated states as well as their reactions. It focuses on understanding the complex structures of the isotope. The simplest structures are nucleons (neutrons N and protons Z), which have almost the same mass. Energy levels and the probability of electric transition is in acceptable agreement with the available experimental data [1]. The isotope is a group of N and Z confined to an area of fm10 or less [2]. Nuclear structure physics is dedicated to studying the properties of nuclei at low excitability energies where single energy levels can be solved. This means that quantitative effects are usually prevalent and that the states of isotope are of a very complex structure [3,4]. The aim of this study was to calculate the energy levels and reduced electric quadrupole transition probability for ^{22}F isotope using Oxbash code. Oxbash is a set of codes for carrying out shell-model calculations with dimensions up to about 50,000 in the J-T scheme and about 2,000,000 in the M-scheme. Oxbash comes with a library of model spaces and interactions. It is a set of symbols for carrying out the shell model calculations and it comes with the library of space model and interactions and differs from other programs in the language and method of performing calculations and speed. It started in Argentina in 1976 and it is a powerful computer system for calculating the energy levels of light and medium nuclei. The Oxbash program was chosen as it is a universal and modern program to achieve the goal of research.

EXPERIMENTAL METHODS

It is believed that the system consists of single particles moving in determined orbits. Each orbit contains a particular energy, an angular momentum, and an equivalence related to it. The total angular momentum and symmetry can be anticipated. The shell is filled with nucleons according to Powelly principle resulting in a certain number of these particles which occupy a certain energy level leading to the closed shell concept. When the shell is

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filled, any additional particles of the kind should be placed in a different level (shell) [5,6]. There are three types of nuclei in a shell model [7].

1. Closed-Shell Isotope: It contains a full internal shell and an entirely empty external shell.
2. Single-Particle Isotope: It contains full internal shell except for one shell with one particle.
3. Single-Hole Isotope: These are the nuclei that contain a full shell except for one shell that is not entirely full and needs a single nucleon.

When applying the model, a potential should be selected. There are different kinds of potentials that explain the magical numbers. Among these potentials is the infinite square well potential of the radius R.

$$V = \begin{cases} 0 & r < R \\ \infty & r \geq R \end{cases} \quad (1)$$

and harmonic oscillator potential:

$$V = \frac{1}{2} m_0 \, \omega^2 r^2 \quad (2)$$

where w is the oscillator frequency of the mass m_0 [8]. The nuclear potential of the most realistic form is the harmonic oscillator potential (Woods –Saxon potential). It does not require a non-finite separation energy and does not sharp energies as in the following formula [9].

$$V(r) = \frac{-V_0}{1+\exp[(r-R)/a]} \quad (3)$$

where V_o is the well depth (V_o ~ 50 MeV), r is the distance from the center to the isotope roof, isotope radius is (R = 1.2 $A^{1/3}$ fm), and a is the shell thickness (a = 0.524 fm).

Any possible potential can give the shell order (square potential, simple harmonic potential, Saxon-Wood potential). There are two basic principles in shell model. First, the closed core which consists of a closed shell. Second, the residual interaction between Valence nucleons, which is defined as a set of single particle energies and two particle matrix elements. They are designed for an area of certain model. This reaction causes an excitement to the potential energy (u) of the isotope which is equal to the sum of the potential of the two particles [10,11].

$$U = \sum_{i<j} Vij \quad (4)$$

when adding the reciprocal effect to the Hamilton effect, then

$$H = H_0 + \sum_{i<j} V_{ij} \quad (5)$$

where V_{iJ} is the reciprocal effect of two particles.

The reactions of an area of a certain model is determined. It consists of single particle energies (SPE) and two particle matrix elements (TBME). The single particle energy is derived from the nucleon core + nucleon. For the two particle matrix, two methods are used: theoretical and experimental. It is calculated by the nucleon-nucleon reaction [12]. The closed shell is treated as vacuum since the nucleons there do not change; therefore, the Hamilton that controls the dynamics of the equivalence nucleons is represented by the sum of single particle energies and the residual reaction of nucleons and is formulated as [13].

$$H_i = \sum_i H_0 + \sum_{i<j} V_{ij} \quad (6)$$

where:
H_0 is the independent Hamilton particle
V_{ij} is the residual nucleons reaction

For calculating the shell model, the harmonic oscillator potential was used for its simplicity. The deviation equation of the symmetrical spherical potential of the nucleon is written as [13].

$$\hat{H}\,\Psi(r) = E\,\Psi(r) \quad (7)$$

and the following equation could be formulated:

$$\hat{H} = T + V = \frac{\hat{P}^2}{2M_P} + V(r) \quad (8)$$

where:
$\hat{H}$ is the Hamilton effect
$\Psi(r)$ is the wave function
$\hat{P}$ is the linear momentum effect
E is the internal value
$V(r)$ is he potential effect

By compensating the Hamilton effect in the Eq. (7), the following second degree differential equation is formulated [14].

$$\left[-\frac{\hbar^2}{2M_P}\nabla^2 + V(r)\right]\Psi(\vec{r}) = E\,\Psi(\vec{r}) \quad (9)$$

To apply this software, the model space and reaction should be determined. After selecting the space, the Valence nucleons are examined. This system regulates a set of possible earthly conditions then makes the matrix JT based on a set of linear components of earthly conditions to give the suitable values of T and J. After selecting the reaction, Hamilton builds the problem and executes the calculations [15-17] and uses the software package (SHELL) to establish the matrix elements of a single particle density (OBDME). The software package (LPE) is used to calculate the wave function and levels of energy. The aim of the current study

was to calculate the levels of energy and quadrupole transitions probability of B (E2) using the harmonic oscillator potential. There were different active reactions used such as PW, CWH for the isotope ^{22}F. OXBASH software was used to execute the calculations in the sd model space for the isotope of ^{22}F that contains six nucleons distributed as one proton and five neutrons outside the closed core $^{8}O_{8}^{16}$ which occupies the shell model $Od_{5/2}$, $1s_{1/2}$, $Od_{3/2}$ according to Powelly principle.

RESULTS AND DISCUSSION

A comparison was conducted between the theoretical values of energy levels in relation to the Ground state of the ^{22}F isotope (using the potential of PW and CWH) and the experimental values available according to the total angular momentum values and symmetry as shown in Table 1 and Fig. 1.

By studying the energy levels of the ^{22}F nuclei and applying the nuclear shell model and the PW reaction, it was found that: (1). The total angular momentum of the ground level 4^{+}_{1} was confirmed when compared to the available experimental values. There was a significant consistency in the calculated energy values (1.063, 2.350, 2.624 MeV) with the available experimental values of energy of the same angular momentum and symmetry (1^{+}_{1},4^{+}_{2}, 1^{+}_{3}). (2). The total angular momentum and symmetry of the unidentified experimental energies were confirmed with total angular momentum and symmetry (3^{+},2^{+},5^{+},3^{+},2^{+},0^{+},2^{+},2^{+},5^{+},4^{+},2^{+},0^{+},4^{+},2^{+},3^{+},0^{+}) after comparing with the calculated values. (3). The confirmed calculations of theoretical energies were inconsistent with any obtained experimental value. The experimental energy values (5.590, 5.750, 6.595 MeV) of the experimentally unidentified angular momentum were determined with total angular momentum and symmetry (6^{+},6^{+},1^{+}). (4). Thirty four values of the calculated theoretical energy of momentum and symmetry were inconsistent with any experimental value. The highest theoretical energy value was (21.202 MeV), whereas the highest experimental value was (6.595 MeV).

Table 1. A comparison between the theoretical values of energy levels using the potential of PW, CWH, and the experimental values available according to the total angular momentum values and symmetry.

J^{π}	E (MeV) Theoretical	E (MeV) Experimental	J^{π}
4^{+}_{1}	0.000	0.000	(4^{+})
3^{+}_{1}	0.106	0.071	(3^{+})
2^{+}_{1}	0.285	0.310	(2^{+})
1^{+}_{1}	1.063	1.627	1^{+}
5^{+}_{1}	1.266	1.413	(5^{+})
3^{+}_{2}	1.365	1.632	(3^{+})
2^{+}_{2}	1.559	2.006	(2^{+})
1^{+}_{2}	2.090	……	……
4^{+}_{2}	2.350	2.580	4^{+},5^{+}
0^{+}_{1}	2.365	2.920	(1^{+},0^{+})
2^{+}_{3}	2.521	2.881	(2^{+})
1^{+}_{3}	2.624	2.571	1^{+}
3^{+}_{3}	2.702	……	……
2^{+}_{4}	3.194	3.376	(1^{+},2^{+})
5^{+}_{2}	3.283	3.581	(5^{+})
3^{+}_{4}	3.544	……	……
4^{+}_{3}	3.591	4.200	(4^{+},5^{+})
1^{+}_{4}	3.883	……	……
2^{+}_{5}	3.918	3.980	(2^{+},3^{+})
0^{+}_{2}	4.089	3.170	(0^{+},1^{+})
3^{+}_{5}	4.151	……	……
2^{+}_{6}	4.168	……	……
1^{+}_{5}	4.295	……	……
4^{+}_{4}	4.353	4.366	(3^{+},4^{+})
2^{+}_{7}	4.441	……	……
5^{+}_{3}	4.501	……	……
6^{+}_{1}	4.515	……	……
1^{+}_{6}	4.659	……	……
2^{+}_{8}	4.679	4.630	(2^{+},3^{+})
3^{+}_{6}	4.738	4.780	(2^{+},3^{+})
4^{+}_{5}	4.964	…….	…..
0^{+}_{3}	5.141	5.238	(0^{+},1^{+})
5^{+}_{4}	5.200	……	……
3^{+}_{7}	5.252	……	……
4^{+}_{6}	5.364	……	……

1_7^+	5.369	……	……
3_8^+	5.425	……	……
2_9^+	5.524	……	……
3_9^+	5.548	……	……
6_2^+	5.591	5.590	…..
4_7^+	5.781	……	……
6_3^+	5.782	5.750	……
1_8^+	5.938	……	……
5_5^+	5.943	……	……
2_{10}^+	5.954	……	……
3_{10}^+	6.219	……	……
7_1^+	6.278	……	……
4_8^+	6.338	……	……
5_6^+	6.567	……	……
1_9^+	6.587	6.595	……
4_9^+	6.962	……	……
5_7^+	7.155	……	……
4_{10}^+	7.214	……	……
1_{10}^+	7.292	……	……
7_2^+	7.294	……	……
0_4^+	7.592	……	……
5_8^+	7.665	……	……
6_4^+	7.724	……	……
8_1^+	8.104	……	……
5_9^+	8.112	……	……
6_5^+	8.177	……	……
5_{10}^+	8.339	……	……
7_3^+	8.560	……	……
6_6^+	9.116	……	……
0_5^+	9.319	……	……
6_7^+	9.369	……	……
0_6^+	9.632	……	……
7_4^+	9.774	……	……
6_8^+	9.952	……	……
7_5^+	10.037	……	……
0_7^+	10.246	……	……
6_9^+	10.282	……	……
8_2^+	10.681	……	……
6_{10}^+	11.098	……	……
0_8^+	11.438	……	……
7_6^+	11.535	……	……
9_1^+	12.296	……	……
0_9^+	12.385	……	……
7_7^+	12.404	……	……
8_3^+	12.718	……	……
0_{10}^+	12.844	……	……
7_8^+	13.097	……	……
8_4^+	13.542	……	……
7_9^+	13.738	……	……
7_{10}^+	14.362	……	……
8_5^+	14.476	……	……
8_6^+	15.675	……	……
9_2^+	15.681	……	……
8_7^+	16.955	……	……
8_8^+	18.594	……	……
9_3^+	19.844	……	……
8_9^+	19.983	……	……
8_{10}^+	21.202	……	……

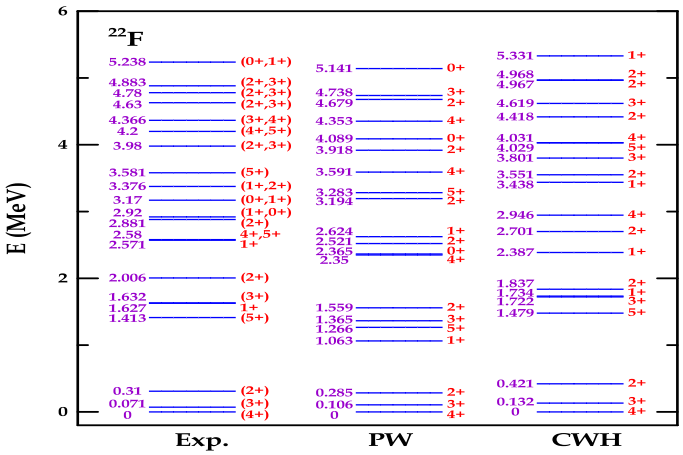

Fig. 1. The theoretical values of energy levels in relation to the ground state of ^{22}F isotope with the experimental results through PW, CWH.

Table 2 and Fig. 1 illustrate a comparison between the theoretical values of energy levels in relation to the ground state of ^{22}F isotope (using CWH potential) and the available experimental values [18-24]. After examining the energy levels of ^{22}F by applying the nuclear shell model of the reaction CWH, it was found that: (1). The total angular momentum of the ground level 4^+_1 was confirmed when comparing with the experimental values. (2). A significant consistency was obtained of the calculated energy values (1.734, 2.387, 2.946 MeV) with the available experimental values of the same angular momentum (1^+_1,1_2^+,4^+_2). (3). The angular momentum of the experimental energies was confirmed of the experimentally unidentified angular momentum that were determined with total angular momentum and symmetry (3^+,2^+,5^+,3^+,2^+,2^+,1^+,2^+,3^+,5^+,4^+,3^+,2^+,2^+,1^+). (4). The angular momentum of the experimental energy of the unidentified angular momentum MeV (4.366) was as expected to be 2^+. (5). Theoretical energy values were obtained inconsistent with any of the available experimental values with a total angular momentum and symmetry (0^+_1,3^+_3,1^+_4,1^+_5,6^+_1,5^+_3,4^+_4,2^+_8,0^+_2,4^+_5,3^+_6,1^+_7,4^+_7,5^+_4,2^+_9,3^+_8,1^+_8,2^+_{10},3^+_9,5^+_5).

Table 2. Comparison between the theoretical values of energy levels using CWH potential and the available experimental values [18].

J^π	E (MeV) Theoretical	E (MeV) Experimental	J^π
4^+_1	0.000	0.000	(4^+)
3^+_1	0.132	0.071	(3^+)
2^+_1	0.421	0.310	(2^+)
5^+_1	1.479	1.413	(5^+)
3^+_2	1.722	1.632	(3^+)
1^+_1	1.734	1.627	1^+
2^+_2	1.837	2.006	(2^+)
0^+_1	2.245	……..	……
1^+_2	2.387	2.571	1^+
3^+_3	2.617	……..	.....
2^+_3	2.701	2.881	(2^+)
4^+_2	2.946	2.580	4^+,5^+
1^+_3	3.438	3.170	(0^+,1^+)
2^+_4	3.551	3.376	(1^+,2^+)
3^+_4	3.801	3.980	(2^+,3^+)
5^+_2	4.029	3.581	(5^+)
4^+_3	4.031	4.200	(4^+,5^+)
1^+_4	4.150	……	……
2^+_5	4.418	4.366	(3^+,4^+)
3^+_5	4.619	4.630	(2^+,3^+)
1^+_5	4.791	……	……
6^+_1	4.876	……	……
5^+_3	4.889	……	……
2^+_6	4.967	4.780	(2^+,3^+)
2^+_7	4.968	4.883	(2^+,3^+)
4^+_4	5.079	…..	……
2^+_8	5.323	……	….

1_6^+	5.331	5.238	$(0^+,1^+)$
0_2^+	5.340	……	……
4_5^+	5.390	……	……
3_6^+	5.506	……	……
4_6^+	5.565	5.590	……
1_7^+	5.705	…….	……
3_7^+	5.742	5.750	……
4_7^+	5.818	……	……
5_4^+	5.865	……	……
2_9^+	5.885	……	……
3_8^+	6.037	……	……
1_8^+	6.170	……	……
2_{10}^+	6.211	……	……
3_9^+	6.308	……	……
5_5^+	6.608	……	……
6_2^+	6.682	6.595	……
3_{10}^+	6.736	……	……
0_3^+	6.746	……	……
6_3^+	6.813	……	……
1_9^+	6.827	……	……
7_1^+	6.992	……	……
4_8^+	6.993	……	……
4_9^+	7.146	……	……
5_6^+	7.398	……	……
1_{10}^+	7.455	……	……
4_{10}^+	7.817	……	……
5_7^+	8.174	……	……
0_4^+	8.337	……	……
5_8^+	8.357	……	……
5_9^+	8.451	……	……
0_5^+	8.505	……	……
7_2^+	8.599	……	……
6_4^+	8.642	……	……
6_5^+	8.894	……	……
5_{10}^+	9.008	……	……
7_3^+	9.264	……	……
8_1^+	9.538	……	……
6_6^+	9.565	……	……
0_6^+	9.642	……	……
0_7^+	10.114	……	……
6_7^+	10.303	……	……
7_4^+	10.503	……	……
6_8^+	10.598	……	……
6_9^+	10.802	……	……
7_5^+	11.015	……	……
8_2^+	11.841	……	……
6_{10}^+	11.845	……	……
0_8^+	11.946	……	……
0_9^+	12.139	……	……
7_6^+	12.504	……	……
0_{10}^+	12.732	……	……
7_7^+	12.954	……	……
9_1^+	13.596	……	……
8_3^+	13.848	……	……
7_8^+	14.161	……	……
7_9^+	14.497	……	……
8_4^+	14.505	……	……
7_{10}^+	14.913	……	……
8_5^+	14.973	……	……
9_2^+	16.888	……	……
8_6^+	17.017	……	……
8_7^+	17.403	……	……
8_8^+	19.110	……	……
8_9^+	20.215	……	……
9_3^+	20.281	……	……
8_{10}^+	21.100	……	……

Also, there were fifty new values of the calculated energy above the experimental energy. The highest calculated energy was (21.100 MeV) and the highest experimental energy was (6.595 MeV). Information of nuclei can be obtained by studying the electromagnetic transitions through the harmonic oscillator potential (H0,b). The transition B(E2) was selected, which is reduced electric transition, using the PW, CWH reactions and OXBASH code. Table 3 shows the B(E2) values of the isotope ^{22}F which were obtained by the PW reaction of the units e^2fm^4. New transitions were also obtained (experimental values are not available yet). Table 4 shows the B (E2) values of the isotope ^{22}F obtained from the CWH reaction. Experimental values of this isotope are not available yet with the units e^2 fm^4. New transitions were obtained.

Table 3. B(E2) values of the isotope ^{22}F obtained from the PW reaction.

$J_i \rightarrow J_f$	**PW Results** ep =en =0.350e	**Experimental** $B(E2)$, e^2 fm^4
$3_1^+ \rightarrow 4_1^+$	72.32	--------
$2_1^+ \rightarrow 3_1^+$	45.31	--------
$5_1^+ \rightarrow 3_1^+$	7.853	--------
$6_1^+ \rightarrow 5_1^+$	63.94	--------
$7_1^+ \rightarrow 6_1^+$	0.1207	--------
$8_1^+ \rightarrow 7_1^+$	10.25	--------
$7_1^+ \rightarrow 5_1^+$	8.237	--------
$2_2^+ \rightarrow 3_2^+$	21.91	--------
$4_2^+ \rightarrow 2_2^+$	52.31	--------
$5_2^+ \rightarrow 3_2^+$	67.82	--------
$6_2^+ \rightarrow 4_2^+$	23.13	--------
$7_2^+ \rightarrow 5_2^+$	25.35	--------
$8_2^+ \rightarrow 6_2^+$	19.74	--------
$8_2^+ \rightarrow 7_2^+$	16.91	--------
$1_3^+ \rightarrow 2_3^+$	2.357	--------
$3_3^+ \rightarrow 1_3^+$	5.221	--------
$4_3^+ \rightarrow 3_3^+$	5.356	--------
$5_3^+ \rightarrow 3_3^+$	4.645	--------
$6_3^+ \rightarrow 4_3^+$	1.000	--------
$7_3^+ \rightarrow 5_3^+$	0.3757	--------
$8_3^+ \rightarrow 6_3^+$	0.2026	--------
$3_2^+ \rightarrow 3_1^+$	10.13	--------
$1_2^+ \rightarrow 2_1^+$	15.03	--------
$4_2^+ \rightarrow 2_1^+$	5.027	--------
$5_2^+ \rightarrow 5_1^+$	6.730	--------
$6_2^+ \rightarrow 4_2$	23.13	--------
$7_2^+ \rightarrow 5_1$	4.802	--------
$8_2^+ \rightarrow 6_1^+$	2.921	--------
$2_3^+ \rightarrow 2_2^+$	26.08	--------
$3_3^+ \rightarrow 4_3^+$	6.886	--------

Table 4. B(E2) values of the isotope ^{22}F obtained from the CWH reaction.

$J_i \rightarrow J_f$	**CWH Results** ep =en =0.530e	**Experimental** $B(E2)$, e^2 fm^4
$3_1^+ \rightarrow 4_1^+$	68.63	--------
$2_1^+ \rightarrow 3_1^+$	41.74	--------
$2_1^+ \rightarrow 4_1^+$	0.4538	--------
$5_1^+ \rightarrow 3_1^+$	7.221	--------
$5_1^+ \rightarrow 4_1^+$	47.37	--------
$1_1^+ \rightarrow 2_1^+$	44.92	--------
$6_1^+ \rightarrow 5_1^+$	65.12	--------
$6_1^+ \rightarrow 4_1^+$	11.86	--------
$7_1^+ \rightarrow 5_1^+$	9.216	--------
$8_1^+ \rightarrow 7_1^+$	11.02	--------
$2_2^+ \rightarrow 3_2^+$	5.991	--------
$1_2^+ \rightarrow 2_2^+$	10.74	--------
$1_2^+ \rightarrow 3_2^+$	46.14	--------
$4_2^+ \rightarrow 2_2^+$	19.57	--------
$5_2^+ \rightarrow 4_2^+$	1.626	--------
$6_2^+ \rightarrow 5_2^+$	2.444	--------
$7_2^+ \rightarrow 6_2^+$	9.095	--------
$8_2^+ \rightarrow 7_2^+$	10.04	--------
$8_2^+ \rightarrow 6_2^+$	5.696	--------
$3_2^+ \rightarrow 4_1^+$	2.541	--------
$3_2^+ \rightarrow 3_1^+$	24.27	--------
$3_2^+ \rightarrow 2_1^+$	1.440	--------
$3_2^+ \rightarrow 5_1^+$	9.881	--------
$2_2^+ \rightarrow 4_1^+$	8.107	--------
$2_2^+ \rightarrow 3_1^+$	7.935	--------
$2_2^+ \rightarrow 2_1$	13.61	--------
$2_2^+ \rightarrow 1_1$	1.084	--------
$4_2^+ \rightarrow 4_1^+$	39.33	--------
$4_2^+ \rightarrow 2_1^+$	15.92	--------
$5_2^+ \rightarrow 4_1^+$	6.274	--------

CONCLUSION

The energy levels of ^{22}F by applying the nuclear shell model of the reaction CWH were found. The total angular momentum of the ground level 4^+_1 was confirmed by comparing with the experimental values. A significant consistency was obtained of the calculated energy values with the available experimental values of the same angular momentum (1^+_1, 1^+_2, 4^+_2). The angular momentum of the experimental energies was confirmed of the experimentally unidentified angular momentum. Then angular momentum was determined by applying a total angular momentum and symmetry. The angular momentum of the experimental energy

(4.366 MeV) of the unidentified angular momentum is expected to be 2^+. Theoretical energy values were inconsistent with any of the available experimental values and also with a total angular momentum and symmetry. Overall, fifty new values of the calculated energy were above the experimental energy as well as the calculated energy, which was higher than the experimental energy.

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