Calculation of Energy Levels and B(E2) for 20Ne Isotope by Using Nuclear Shell Model

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Abstract- In this study, the energy levels and the probability of electric transition B(E2) of the 20Ne nucleus were calculated using the OXBASH code within the sd shell and the use of the effective interaction KUOSD. OXBASH is a computing code to perform a nuclear installation calculation based on a shell mode, Energy levels and the probability of electric transition is acceptable agreement with available experimental data.

Index Terms- OXBASH Code, 20Ne nucleus , Energy Levels, B(E2), sd shell

I. Introduction

One of the criteria to improve investigations of nuclei properties is obtaining the energy levels and nuclear structure of nuclei ,nuclear models have the property to help us to better understanding of nuclear structure which includes main physical properties of nuclei, shell model is one of the most featured and successful nuclear models this model can be compared to the atomic shell model Atomic behaviors and properties can also be described with valence electrons that are outside of a closed shell similarly, nucleon valence (protons or neutrons) in a nucleus is placed outside the closed shell with magic numbers (2,8,20,28,50,82 and 126) play important roles in determining nuclear properties the nucleus with magic numbers is very stable and has completely different properties compared to their neighbors[1]. This model assumes that the nucleons are distributed at separate energy levels according to the Pauli principle, this nucleons move inside a mean field potential produced by the other nucleons[2]. Shell model calculations are performed out within a model space in which the nucleons are limited to a few orbits, when using suitable effective operators, taking into account the effect of the bigger model space ,this model offers a meaningful description of this observable[3].A study of nuclei in the sd shell thus leads to the best understanding between a macroscopic (collective) description and a microscopic description of the nucleus (shell model)[4]. The sd-shell core is considered to be an inert ^{16}O core, on which the valence nucleus is distributed 1d5 / 2, 2s1 / 2 and 1d3 / 2 status[5].

II. Theory

The calculations of the shell model include single-particle energies (SPE) and two-body interaction matrix elements or called two-body matrix elements (TBME), recently this group was named (effective interaction) or (model space Hamiltonian). This model space Hamiltonian can be described in two ways: one method is a "realistic" which is created for a particular shell model space of known data on the free nucleon-nucleon force. The second method is “experimental” which is found in the parameters whose values are specified by agreement between measured level energies and shell model eigenvalue [6].For calculations can be written the shell model Hamiltonian as follows[7].

$$H = \sum_i \varepsilon_i n_i + \sum_{ijkl} V_{ijkl} a_i^\dagger a_j^\dagger a_i a_j$$

Where:

paticale energy of orbit i, -: the single ε_i

n_i : stands for the number operator of the orbit i

V_{ijkl} : the two body matrix elements for the neoclon-neoclon interaction of orbits(i,j,k,l)

$a_i^\dagger$: $a_j^\dagger$, Creation operators

a_i Annihilation operators : a_j ,

It is important to know that there are residual interactions between each of the particles in each case (secondary shells) and that the remaining interactions are observed in the secondary shell if they are partially full, and the angular momentum and parity of the ground state of the nucleus can be determined by the remaining interactions, the nucleic levels of the nucleus have a momentum equal to zero and their positive parity. The nucleons in the secondary shell give double energy in which the values of Mj are inverse and the number of magnetic quantities takes the following values:[8]

$M_j = j\ , (j-1)\ ,\ldots,1/2\ , -1/2\ ,\ldots, -(j-1)\ , -j$

The probability of electric transition can be calculated by equation:[9]

$$B(EL: Ji \rightarrow J f) = \frac{1}{(2J_i+1)} \sum_{M_i M_f M} \left| \left\langle \psi_{J_f M_f} \right\| T_{LM}^{(E)} \left\| \psi_{J_i M_i} \right\rangle \right|$$

$$\left(\frac{2J_f+1}{2J_i+1}\right) \left| \left\langle \psi_{J_f} \right\| T_L^{(E)} \left\| \psi_{J_i} \right\rangle \right|^2 =$$

Where $T_L^{(E)}$ is the electric multipole operator , J_i and J_f are the spin of the initial and final states,respectively

III. Shell Model Calculation

Calculations of energy levels and B(E2) were made with the code OXBASH[10]. OXBASH is using an m-scheme Slater determinant basis with wave functions and good angular momentum J, isospin T is constructed, this program is the only version that uses the projection technology, the sd model spaces contain (0d5/2, 1s1/2, and 0d3/2) above the N = 8 and Z = 8 closed shells for neutrons and protons [11]. Considering the number of valence nucleons for Neon isotopes, the sd model space is the appropriate area for our calculations, Where it is calculated energy level and B(E2) for 20Ne employing harmonic oscillator potential (HO, b), b<0 for Ne isotope within this space . In this work, we focus our attention on the description of energy levels and B(E2) of sd shell of 20Ne isotopes which have configurations(0d5/2, 1s1/2and 0d3/2) ,the sd model space with KUOSD interaction

3.1 Energy levels of ^{20}Ne nucleus

According to the shell model, the ground state of ^{20}Ne nucleus is a closed ^{16}O core , with J =0+ and T=0,the excited states consist of the configuration of the nucleons in the sd-shell .in this work we use KUOSD interaction and single-particle energies (SPEs) are {1d5/2=-4.150,2s1/2=-3.280and 1d3/2=0.930} respectively.The table(1) shows a comparison between theoretical results and available experimental results[12] for Neon isotopes by using KUOSD interaction. From the down table KUOSD Hamiltonians agree reasonably well with experimental data .

The ground state was confirmed 0^+.The agreement is good for the states of with experimental values.

The agreement is good for the states $(3_1^+, 1_1^+, 2_6^+, 2_8^+, 6_9^+, 2_1^+, 4_1^+, 0_2^+, 6_1^+, 2_2^+, 4_2^+, 2_3^+, 2_4^+, 4_3^+, 1_2^+, 8_1^+, 0_3^+, 4_4^+, 2_5^+, 6_2^+, 4_5^+, 4_7^+, 6_3^+, 4_8^+, 8_2^+, 4_9^+, 0_5^+, 6_5^+, 4_{10}^+, 6_6^+, 6_7^+, 6_8^+, 8_3^+)$ as compared with the experimental data. This study also confirmed the angular momentum and parity for energies (11.653,14.455,14,731,14.653,16.010,15.970,17.910)Mev with states $(3_2^+, 2_7^+, 4_6^+, 0_4^+, 2_9^+, 6_4^+, 0_6^+)$ after comparing them with our theoretical values. The total angular momentum values were confirmed without parity for level 2_{10}^+.
The values of experimental energies (13.426,14.313,15.436) Mev were confirmed for angular momentum ($5_2^+, 3_5^+, 3_6^+$) with positive parity.

The agreement is good for angular momentum without parity for state $(5_1^+, 3_3^+, 5_3^+, 7_1^+, 3_7^+, 3_8^+, 3_9^+, 5_7^+, 7_3^+, 5_8^+, 7_4^+, 7_5^+, 3_4^+, 5_5^+, 5_6^+, 7_2^+, 5_{10}^+)$.
The levels of for which the angular momentum and parity are yet unknown at the states $(5_4^+, 1_5^+, 1_6^+, 1_7^+, 0_7^+, 1_8^+, 5_9^+, 1_9^+, 0_8^+ 1_{10}^+, 0_9^+, 6_{10}^+, 0_{10}^+, 3_{10}^+)$

And through our calculations we noticed that the highest energy value is (24.25)Mev for angular momentum and parity 7_5^+ of reaction KUOSD, while the highest experimental value is (28.20)Mev.

Table1.Comparison of the experimental excitation energies[12] and excitation energies predictions for ^{20}Ne nucleus by using KUOSD interactions

J^+(OXBASH)	Energy (OXBASH) KUOSD(ME)	Energy(exp) (Mev)	J(exp)
0_1	0.0	0.0	0^+
2_1	1.455	1.633	2^+
4_1	3.861	4.247	4^+
0_2	6.81	6.725	0^+
6_1	8.188	8.777	6^+
2_2	8.434	7.833	2^+
4_2	10.181	9.990	4^+
2_3	10.374	10.273	2^+
3_1	10.692	10.694	$4^-,3^+$
2_4	11.097	10.940	2^+
4_3	11.188	11.090	4^+
1_1	11.781	11.262	1^+
3_2	11.904	11.653	(3^+)
8_1	12.358	11.951	8^+
5_1	12.482	12.713	5^-
0_3	12.812	12.436	0^+
4_4	12.842	13.048	4^+
2_5	13.185	13.095	2^+
5_2	13.204	13.426	(5^-)
3_3	13.332	13.226	3^-
1_2	13.379	13.307	1^+
6_2	13.412	13.105	6^+
3_4	13.427	13.414	3^-
2_6	13.55	13.592	2^+

1_3	13.629	13.736	1^+
1_4	13.942	14.200	1^+
4_5	14.12	14.270	4^+
2_7	14.382	14.455	$0^+,2^+)($
5_3	14.649	14.816	5^-
4_6	14.733	14.731	(4^+)
0_4	14.865	14.653	(0^+)
3_5	14.931	14.313	(3^-)
7_1	14.972	15.366	7^-
2_8	15.04	15.047	2^+
4_7	15.2	15.330	4^+
6_3	15.235	15.159	6^+
3_6	15.490	15.436	(3-)
4_8	15.856	16.329	4^+
5_4	15.888	------	------
3_7	15.952	16.136	3^-
2_9	15.977	16.010	(2^+)
6_4	16.138	15.970	(6^+)
2_{10}	16.324	16.437	$(0,2,4)^+$
8_2	16.374	16.746	8^+
3_8	16.46	16.628	3^-
5_5	16.566	16.559	5^-
4_9	16.592	16.667	4^+
1_5	16.829	------	------
3_9	17.041	17.284	3^-
0_5	17.155	16.732	0^+
6_5	17.383	17.541	6^+
0_6	17.568	17.910	(0^+)
4_{10}	17.624	17.769	4^+
5_6	17.895	17.851	5^-
1_6	17.941	------	------
7_2	18.037	18.005	7^-
3_{10}	18.038	------	------
6_6	18.174	18.286	6^+
5_7	18.733	18.494	5^-
7_3	18.848	18.768	7^-
1_7	18.873	------	------
0_7	18.94	------	------
6_7	18.988	18.745	6^+
1_8	19.332	------	------
5_8	19.412	19.859	5^-
5_9	19.624	------	------
6_8	19.736	19.655	6^+
1_9	20.264	------	------
0_8	20.45	------	------
6_9	20.466	20.445	6^+
5^{10}	20.476	20.468	5^-
7_4	20.78	20.760	7^-
1_{10}	21.023	------	------
0_9	21.075	------	------
6_{10}	21.802	------	------
0_{10}	22.144	------	------
8_3	22.771	23.40	8^+
7_5	24.254	22.30	7^-

3.2 Reduced electric quadrupole transition prpbability B(E2) Calculation:

The B(E2) has been predicted for the 20Ne isotope nuclei within the nuclear shell model, by using KUOSD interactions. With the harmonic oscillator potential (HO, *b*), the transition probabilities were calculated for $b < 0$ [13]. The comparison between experimental B (E2) and theoretical shows an advantage for KUOSD calculations for many levels. The primary polarization effect was included by selecting the effective charge for proton and neutrons ep = en = 0.350 respectively. Comparison of calculated values with available experiment data [12] is shown in Table.2 ,New electric B(E2) transitions were expected in our results by using (KUOSD) interaction of the studied isotope. transition probabilities B(E2) gives agreeable agreement comparing with experimental data.

Table2.Comparison of the B(E2) results for ^{20}Ne nucleus with the experimental data[12]

$J_j^+ \rightarrow J_i^+$	B(E2) our.Results (e^2 fm^4) e_n=0.350 , e_p=0.350	B(E2) Exp.Results (e^2fm^4)
$2_1 \rightarrow 0_1$	59.04	65.46
$2_2 \rightarrow 0_1$	0.0098	2.35
$4_1 \rightarrow 2_1$	73.53	70.94
$2_2 \rightarrow 2_1$	2.612	5.48
$0_2 \rightarrow 2_1$	13.98	11.60
$3_1 \rightarrow 2_1$	0.0297	
$4_2 \rightarrow 2_1$	3.447	26.76
$1_1 \rightarrow 2_1$	0.3683	
$3_2 \rightarrow 2_1$	0.3011	
$1_2 \rightarrow 2_1$	0.2690	
$2_2 \rightarrow 4_1$	1.186	
$6_1 \rightarrow 4_1$	59.99	64.49
$3_1 \rightarrow 4_1$	0.5387	
$4_2 \rightarrow 4_1$	0.2108	
$3_2 \rightarrow 4_1$	0.1390	
$5_1 \rightarrow 4_1$	0.3331	
$5_2 \rightarrow 4_1$	0.8671	
$6_2 \rightarrow 4_1$	0.7837	
$2_2 \rightarrow 0_2$	18.76	
$4_2 \rightarrow 6_1$	10.49	
$8_1 \rightarrow 6_1$	38.35	29.02
$5_1 \rightarrow 6_1$	2.560	
$5_2 \rightarrow 6_1$	0.04356	
$6_2 \rightarrow 6_1$	0.9021	
$7_1 \rightarrow 6_1$	0.0006437	
$7_2 \rightarrow 6_1$	0.1091	
$8_2 \rightarrow 6_1$	1.464	
$3_1 \rightarrow 2_2$	10.31	
$4_2 \rightarrow 2_2$	0.1504	
$1_1 \rightarrow 2_2$	0.6821	
$3_2 \rightarrow 2_2$	0.8443	
$1_2 \rightarrow 2_2$	0.7005	
$1_1 \rightarrow 3_1$	20.57	
$3_2 \rightarrow 3_1$	8.108	
$1_2 \rightarrow 3_1$	0.04564	
$5_1 \rightarrow 3_1$	26.23	
$5_2 \rightarrow 3_1$	0.2754	
$1_1 \rightarrow 3_2$	28.82	
$1_2 \rightarrow 3_2$	0.007264	
$5_1 \rightarrow 3_2$	0.1324	
$5_2 \rightarrow 3_2$	11.96	
$3_1 \rightarrow 4_2$	3.177	
$3_2 \rightarrow 4_2$	5.354	
$5_1 \rightarrow 4_2$	7.665	

$5_2 \rightarrow 4_2$	13.90	
$6_2 \rightarrow 4_2$	0.07915	
$5_2 \rightarrow 5_1$	1.578	
$6_2 \rightarrow 5_1$	17.20	
$7_1 \rightarrow 5_1$	18.72	
$7_2 \rightarrow 5_1$	1.740	
$6_2 \rightarrow 8_1$	0.8867	
$7_1 \rightarrow 8_1$	4.244	
$7_2 \rightarrow 8_1$	0.4456	
$8_2 \rightarrow 8_1$	2.637	
$6_2 \rightarrow 5_2$	1.162	
$7_1 \rightarrow 5_2$	3.502	
$7_2 \rightarrow 5_2$	0.6213	
$7_1 \rightarrow 6_2$	3.252	
$7_2 \rightarrow 6_2$	0.02658	
$8_2 \rightarrow 6_2$	26.69	
$7_2 \rightarrow 7_1$	5.588	
$8_2 \rightarrow 7_1$	13.41	
$8_2 \rightarrow 7_2$	1.940	
$1_2 \rightarrow 1_1$	9.675	

IV. Conclusions

The calculations were performed using the OXBASH code. The study demonstrated that the interaction files are consistent with the experimental data available newly. Calculations of energy levels and reduced probabilities of the $B(E2)$ transitions for ^{20}Ne were carried out within the sd shell by using effective interaction KUOSD. We deduce the shell model configuration mixing are very successful in this model space . In our calculations, new energy levels have been predicted and many levels that are not experimentally confirmed have been confirmed .

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