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Energy Levels Calculations of ^{28,30}Si and ^{26,28}Al Isotopes Using Shell Model Code OXBASH

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Abstract: In this paper, the energy levels of Si and Al isotopes have been calculated. Calculations were carried out in the SD model space with 13 different potentials using the shell model code OXBASH by applying spin-parity of valance nucleons. OXBASH is a computing code for carrying out calculation of nuclear structure based on shell model. We compared calculated energy levels with experimental results and find the best energy and potential for each isotope.

Keywords: OXBASH Code, SD Model Space, Energy Levels, Silicon and Aluminum isotopes

1. Introduction

Obtaining the nuclear structure and energy levels of nuclei is one of the criteria to improve investigations of nuclei properties. Nuclear models have the property to help us to better understanding of nuclear structure which contains main physical properties of nuclei, and shell-model is one of the most prominent and successful nuclear models. This model can be compared with the electron shell model for atoms. As atomic behavior and properties can be described with valance electrons which exist out of a closed shell, similarly, valance nucleons (protons or neutrons) in a nucleus which are placed out of close shells (with magic numbers 2,8,20,28,50,82 and 126) play important roles in determining nuclear properties. Nuclei with magic numbers are very stable and have completely different properties comparing with their neighbors.

Existence of spatial levels is determined by Pauli Exclusion Principle. By knowing nuclear potentials for all nucleons in a nucleus, one can calculate energy levels.

The object of this paper is to calculate the energies of Si and Al isotopes by using OXBASH code. This program is a set of commands for carrying out shell-model calculations with dimensions up to about 100,000 in the J-T scheme and about 2,000,000 in the M-scheme .We applied the 2005-8 version of this code which can be used on any Windows PC without the use of any other software.

2. Theory and Calculation

OXBASH is a powerful computer code to calculate the energy levels of light and medium nuclei. By using it, we can measure the energy levels of the nucleus and compare it with experimental data. One of the most important challenges in nuclear physics is to calculate and measure energy levels of medium and heavy nuclei by using shell model theory. As a result, it is important to check computer codes in this area. There are many codes written for this purpose such as: NutShell, REDSTICK, ANTOINE, OXBASH, etc. In this paper we are using OXBASH code, a code which has been developed in this field for many years.

Experimental studies on the stability of some nuclei show that nuclei with protons or neutrons numbers (2, 8, 20, 50, 82, etc.) are more numerous and stable. In other words, the existence of these magic numbers suggests shell model structure in nuclear physics similar to atomic physics. In this paper, the energy levels of Si and Al isotopes have been measured using the code OXBASH. The program includes a set of computational code which is based on the ability to measure the energy levels by forming ground state matrices with dimensions up to 2000000 and JT matrix with dimension up to 100,000. The version of this code is 2005-8 which can be installed and used on any operating system without using any other additional software.

Space model SD

Considering the number of valence nucleons for Silicon and

magnesium isotopes, SD model space is the suitable model for these calculations. This model consists of $2s_{1/2}$، $1d_{3/2}$ و $1d_{5/2}$ valence orbitals. Figure 1 shows the PF and SD model spaces according to shell model theory.

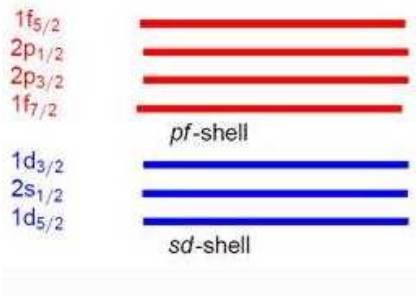

Figure 1. *PF and SD model spaces*

The basis of Hamiltonian in shell model calculations is normalized Green matrix. For SD model space in OXBASH code, 13 different interaction potentials to perform computations on different nuclei is included [4].

The first normalized G matrix was introduced in 1960 which its results were in good agreement with experimental data for A = 18 to A = 38 nuclei [9, 10], however, with increasing nucleon numbers, solving this matrix was very difficult [11]. In 1976 for the bottom layer of SD model space, the Hamiltonian CWH [7, 8] was introduced and in 1984 the potential W was introduced for the entire layer SD [12].

OXBASH code is a computer program that is described with a set of model spaces and interactions to apply in shell model calculations with high dimensions.

In order to use this code one should specify the model space and interaction. In other words after choosing appropriate model space which is chosen considering valance nucleons, this code constructs a set of possible ground states and then makes JT matrix based on linear combination of ground states which give suitable T and J values. Finally by choosing the desirable interaction potential it constructs the Hamiltonian of the problem and carries out the calculations and as a default gives 10 lowest energies.

The applied model space illustrates the orbitals which are considered in calculations using main shells in shell-model theory.

Considering the number of valance nucleons of these isotopes, the suitable space for related calculations of these nuclei is SD space. The SD model space includes the $1s_{1/2}$, $1d_{5/2}$ and $1d_{3/2}$ orbitals and 13 different interaction potentials which are considered in this model space are: SDBA, KUOSD, KUOSDM, BKUOSD, PW, CW, W, CWH, KUOSDH, SDM, W, HBUSD, HBUMSD and SU3SD.

$^{28}{}_{14}$si and $^{30}{}_{14}$si have 12 and 14 valence nucleons with positive parity respectively and their isospins are 0 and 1 respectively. Their angular momentum levels are 0-13 and 0-14, respectively. Since all the experimental data of the energy levels of the isotopes under study have not been obtained, only the known data are given in Tables (1) and (2). Also the isotopes $^{26}{}_{13}$AL and $^{28}{}_{13}$AL have 10, 12 valence nucleons with positive parity respectively and their isospins are 0 and 1 respectively. Their angular momentum levels are 0-13. The calculated energies along with the experimental energies are shown in tables 3 and 4.

The basis of the Hamiltonian in shell model calculations is the suitable normalized Green matrix for the problem [4, 5]. In this paper calculations carried out for all 13 potentials separately for the above isotopes.

The first normalized G matrix for SD space model has been suggested in 1960 and its results were in good agreement with experimental spectrum for A=18 to A=38 [1, 2, 3] but in case of temperature increase it fails [6]. CWH Hamiltonian was suggested for the lower part of SD layer in 1976 [7, 8] and the W potential introduced for total SD layer in 1984 [6].

Tables 1 and 2 show results obtained by executing OXBASH code in SD space model for different interacting potentials for Si isotopes and figure 2 shows their related curves.

Table 1. *^{28}Si energy levels calculations with different potentials.*

J	Experimental	BKUOSD	HBUMSD	HBUSD	KUOSDM	SDM	W
0	4.979	2.828	4.663	4.429	3.944	5.044	5.011
1	8.328	8.547	9.034	8.569	8.643	8.271	9.399
2	7.381	7.437	7.334	7.956	7.783	7.192	7.522
3	7.799	7.666	8.240	7.684	7.295	7.775	8.139
4	6.889	6.351	6.996	6.632	6.665	6.724	7.037
5	8.945	8.662	9.233	8.747	8.773	9.089	9.232
6	8.854	8.371	8.928	8.380	8.318	8.771	8.459
7	-	9.063	13.233	12.893	13.139	10.307	12.810
8	14.643	12.864	14.642	14.858	15.037	14.712	14.973

Table 2. *^{30}Si energy levels calculations with different potentials.*

J	Experimental	CW	HBUMSD	KUOSD	PW	SDBA	W
0	3.788	4.089	4.479	4.048	3.259	4.106	3.681
1	7.634	7.285	7.183	7.441	6.836	8.037	7.721
2	3.499	3.256	3.502	2.830	3.396	2.811	3.153
3	4.831	4.782	4.944	4.567	4.886	4.727	4.511
4	5.280	5.411	5.164	5.324	5.103	5.141	5.472
5	6.999	7.536	7.508	6.732	7.374	7.240	7.038
6	9.371	9.197	9.753	9.442	9.488	9.442	9.034

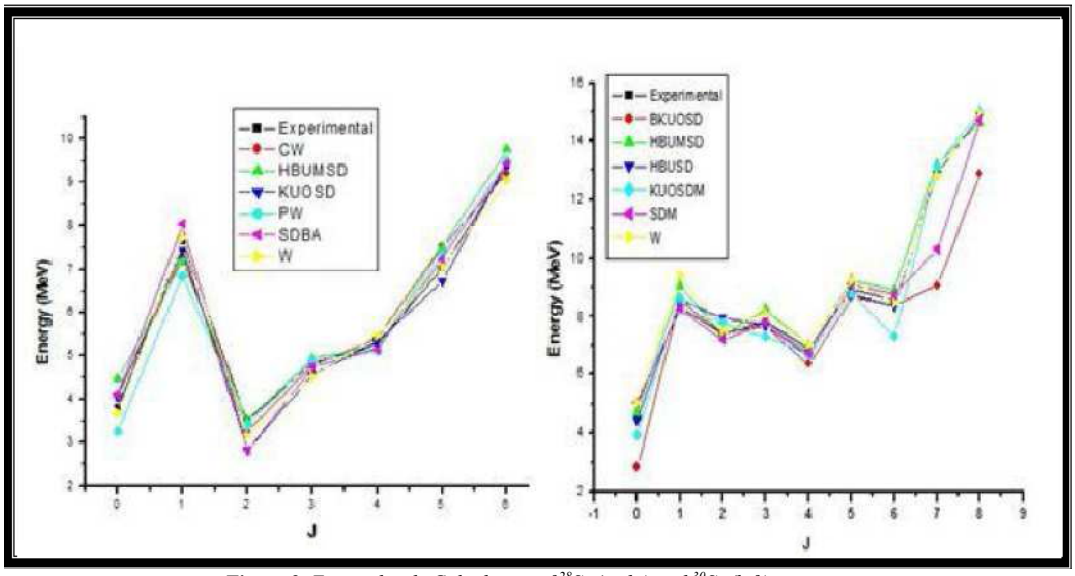

Figure 2. *Energy levels Calculation of ^{28}Si (right) and ^{30}Si (left) isotopes.*

By executing this code in SD space for ^{26}Al we obtained energy levels and which are shown in table 3 and figure 3.

Table 3. *^{26}Al energy levels calculations with different potentials.*

J	Experimental	BKUOSD	HBUMSD	HBUSD	KUOSDM	SDM	W
0	4.458	4.576	5.248	3.559	4.799	4.57	4.157
1	1.058	1.222	0.858	0.887	1.074	0.986	0.97
2	1.759	1.17	1.856	1.917	2.027	1.275	1.99
3	0.417	0.297	1.042	1.082	0.682	0.695	0.316
4	2.069	0.884	2.129	2.206	2.188	1.931	1.969
5	3.403	1.338	1.796	1.981	3.172	2.167	2.469
6	3.507	2.719	3.416	3.513	3.798	3.664	3.58
7	3.922	3.492	4.095	3.588	3.806	4.035	4.173

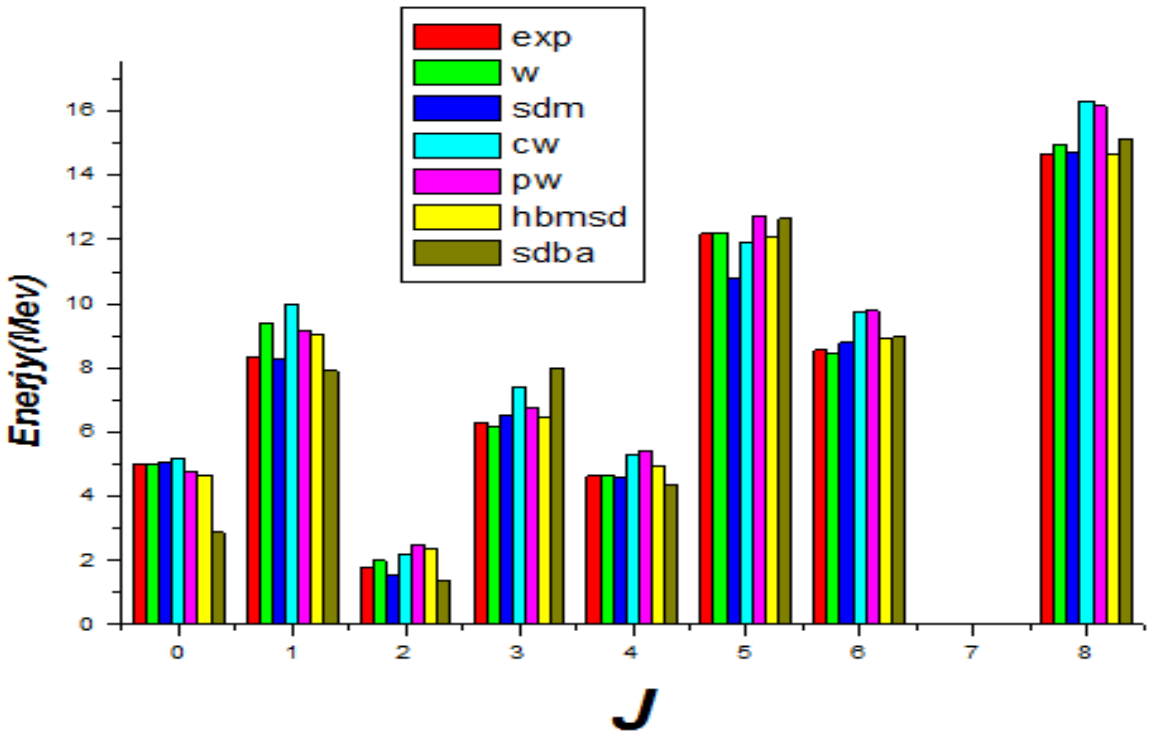

Figure 3. *Energy levels Calculation of ^{26}Al.*

The resulted data for ^{28}Al has been shown in table 4 and figure 4.

Table4. *^{28}Al energy levels calculations with different potentials.*

J	Experimental	SDBA	HBMSD	PW	CW	SDM	W
0	4.979	2.865	4.663	4.777	5.196	5.044	5.011
1	8.328	7.9	9.034	9.132	10.002	8.271	9.399
2	1.779	1.35	2.353	2.473	2.207	1.54	1.987
3	6.276	7.992	6.491	6.756	7.373	6.528	6.167
4	4.614	4.345	4.966	5.402	5.308	4.582	4.659
5	12.175	12.641	12.084	12.703	11.893	10.772	12.202
6	8.543	8.952	8.928	9.765	9.753	8.771	8.459
7	14.643	15.139	14.642	16.157	16.307	14.718	14.973

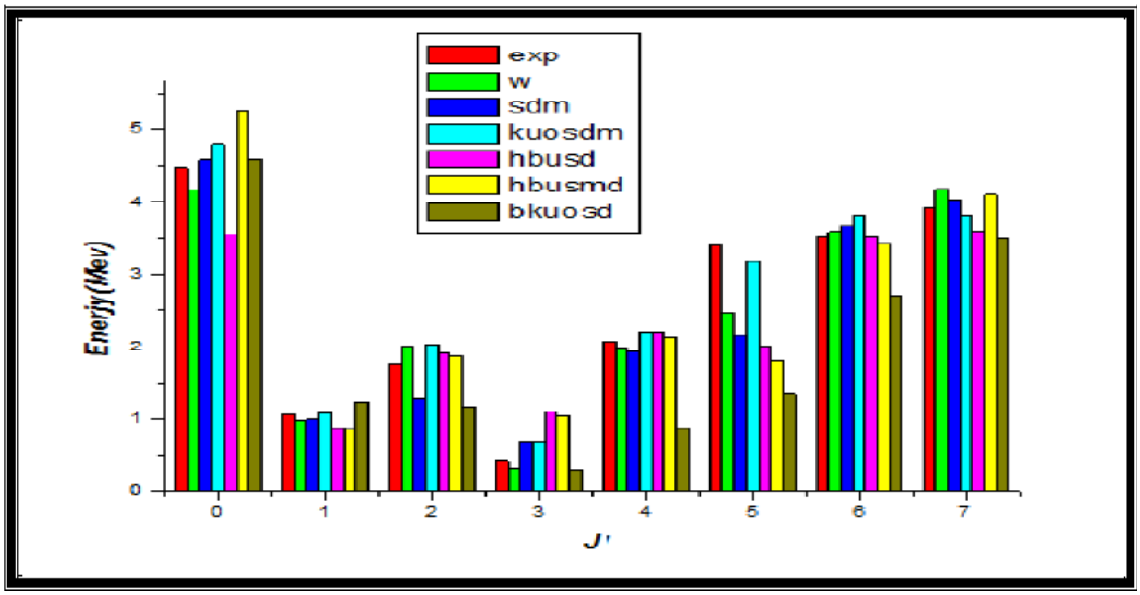

Figure 4. *Energy levels Calculations of ^{28}Al.*

3. Conclusions

We have compared calculated results for energy levels which are obtained by running OXBASH code for 13 different interacting potentials in SD space model for two isotopes of Si and Al nuclei and comparing them with experimental data. As it shows, the results for W interaction overall are in good agreement with experimental data meanwhile in some cases comparison between levels shows good fit for some other interactions.

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