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Calculating Energy Levels in ^{25}Mg/^{25}Al Mirror Nuclei

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Authors' contributions

This work was carried out in collaboration between all authors. Author AN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MB and SM managed the analyses of the study. Author SM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Coulomb Displacement Energies in mirror nuclei ^{25}Mg, ^{25}Al have been calculated using shell model code OXBASH [1] and compared with experimental results. The code calculations were done in the USD model space with the W Hamiltonian [2]. The OXBASH code which is based on famous nuclear model, the shell model, deals with evaluating energy levels in nuclei. A comparison had been made between our results and the available experimental data [3] to test theoretical shell model description of nuclear structure in mirror nuclei. The energy states of mirror nuclei are almost identical, except for the small effects due to Coulomb interaction where the symmetry in being broken. Energy spectrum calculated with this code was in good agreement with the published experimental data [3].

Keywords: Mirror nuclei; OXBASH code; shell model structure; model space; energy levels.

1. INTRODUCTION

The energy states of mirror nuclei (nuclei with the same mass number and the number of protons (Z) in one of them equals the number of neutrons (N) in the other) are almost identical, except for the small effects due to Coulomb interaction where the symmetry in being broken. The study

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of this symmetry breaking reveals details of the mirror nuclei structure. This shift in mirror symmetry will be observed mostly as a function of spin, where the protons and/or neutrons rearrange themselves in new shell model orbits and hence cause changes in Coulomb energy differences. These effects, known as Coulomb Displacement Energies (CDE), have been the subject of several studies in nuclear structure physics [4,5,6].

Measuring energy levels of nuclei is very important to improve investigations of nuclei properties. Nuclear models can help us to understand nuclear structure which contains main physical properties of nuclei, and shell-model is one of the most prominent and successful nuclear models [7-13]. This model is very similar 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.

One of the most attractive features of the spherical shell model is its relative simplicity for calculations in a strongly restricted configuration space. If the space is sufficiently truncated (i.e. beyond closed shells), one can perform exact shell model calculations which make the comparison with experiments more transparent and hence more attractive also for experimentalists. However, with any reasonable model space truncation one is always left with the problem of determining an effective residual interaction for the nucleons in the considered orbits, usually assumed to be a two-body force [2]. Clearly, the smaller the number of orbitals considered in the calculations, the smaller the number of two-body matrix elements one has to deal with. Since it is a nontrivial problem to establish the two-body matrix elements for a shell model calculation, the uncertainties might increase with a larger shell mode space, although in principle one should get better agreement with experiment.

It has to be recalled that ^{25}Mg / ^{25}Al are mirror nuclei in the SD shell, and that their level schemes should be identical in that configuration space.

For light nuclei, there are many standard effective interactions for the *p* and *SD* model spaces, respectively [14,15]. Analysis of neutron-rich nuclei in the SD model space has been of high interest in recent years as they present new aspects of nuclear structure .Traditional shell-model studies have recently received a renewed interest through large scale shell-model computing in no-core calculations for light and medium nuclei. It is now therefore fully possible to work to large-scale shell-model data and study the excitation levels for heavier nuclei. In these systems, inert core is assumed and space is determined by considering shell gaps. Figure 1 shows the PF and SD model spaces according to shell model theory.

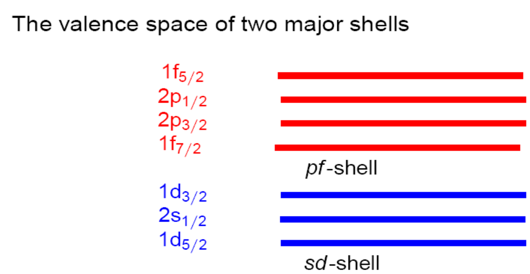

Fig. 1. SD and PF shell model spaces

2. CALCULATIONS

In order to calculate the nuclear energy levels of both ground and excited states based on the nuclear shell model, one needs to have wave functions of those states. These wave functions are obtained by using the shell-model code OXBASH [1]. 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. In this paper, the energy levels of ^{25}Mg / ^{25}Al and mirror nuclei have been calculated using the code OXBASH. This programming code 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. Considering the number of valence nucleons for these mirror nuclei, SD model space is the most suitable model for these calculations which assign separate orbitals for protons and neutrons. This model consists of $d_{5/2}$, $s_{1/2}$ and $d_{3/2}$ valence orbitals. The windows version of this code has been used to calculate the nuclear structure for the above nuclei by employing the SD model space with the W effective interaction [2].

3. DISCUSSION

The results concerning ground and excitation energies of the ^{25}Mg/^{25}Al Mirror Nuclei are presented in this section. Table 1 shows data for ^{25}Mg isotope [16, 17] and table 2 shows data for ^{25}Al isotope [18]. The second column is spin of states, column three the calculated energies by OXBASH code and column four the measured energies [3].

Table 1. Data for ^{25}Mg. All energies are in MeV

	J	E (OXBASH)	E (EXP)
1	$J = \frac{3}{2}$	0.456	0.974
2	$J = \frac{7}{2}$	0.982	1.611
3	$J = \frac{5}{2}$	1.350	1.964
4	$J = \frac{3}{2}$	2.164	2.801
5	$J = \frac{9}{2}$	3.245	3.405
6	$J = \frac{5}{2}$	4.123	3.907
7	$J = \frac{7}{2}$	5.236	5.012
8	$J = \frac{1}{2}$	5.474	5.474
9	$J = \frac{11}{2}$	5.400	5.536
10	$J = \frac{5}{2}$	6.050	6.082
11	$J = \frac{11}{2}$	7.223	7.493
12	$J = \frac{1}{2}$	8.763	8.834

Table 2. Data for ^{25}Al. All energies are in MeV

	J	E (OXBASH)	E (EXP)
1	$J = \frac{3}{2}$	0.456	0.944
2	$J = \frac{5}{2}$	1.350	1.789
3	$J = \frac{7}{2}$	2.233	1.612
4	$J = \frac{3}{2}$	2.164	2.673
5	$J = \frac{9}{2}$	3.245	3.424
6	$J = \frac{11}{2}$	4.123	4.583
7	$J = \frac{5}{2}$	4.449	4.564
8	$J = \frac{1}{2}$	5.474	5.285
9	$J = \frac{5}{2}$	5.713	5.809
10	$J = \frac{3}{2}$	6.322	6.112
11	$J = \frac{11}{2}$	7.824	7.642
12	$J = \frac{1}{2}$	8.764	8.853

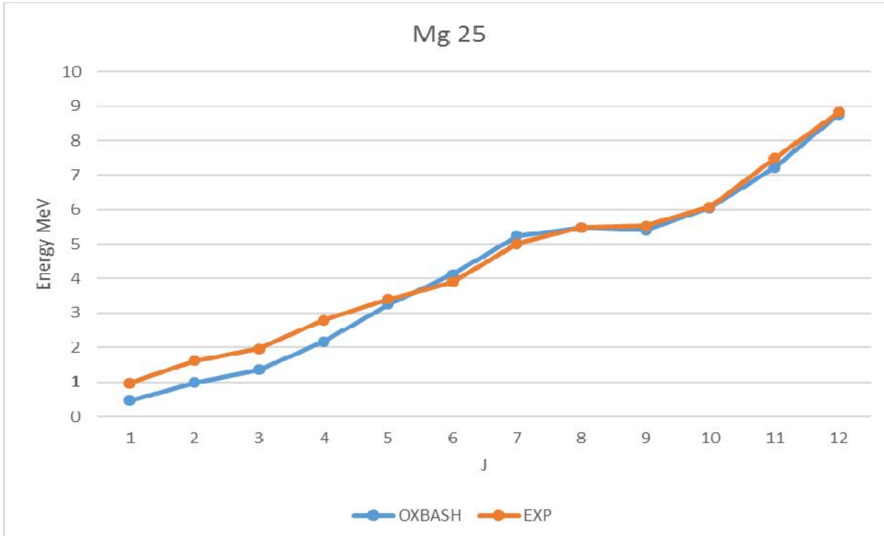

Fig. 2. Calculated and measured energies of ^{25}Mg

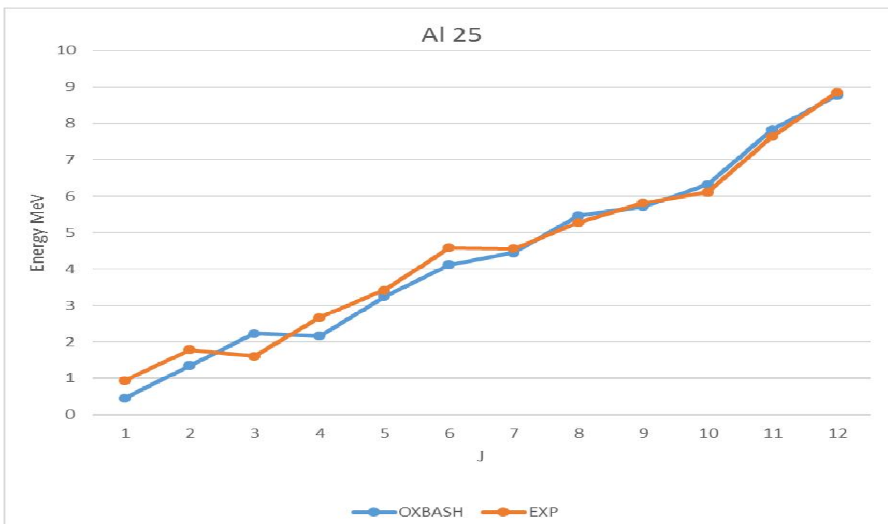

Fig. 3. Calculated and measured energies of ^{25}Al

Figs. 2 and 3 shows calculated and measured energies of ^{25}Mg and ^{25}Al respectively. Due to very small measured errors, they have not shown here. Also, for code calculations there are no any errors. As it can be seen, there is relatively good agreement between calculations made by OXBASH code and measured energies.

4. CONCLUSIONS

Coulomb Displacement Energies in mirror nuclei ^{25}Mg / ^{25}Al (the Z of the first nucleus must equal the N of the second and thus the N of the first equals the Z of the second) have been calculated using shell model code OXBASH and compared with experimental results. These calculations were done in the in the USD model space with the W Hamiltonian. The results show that the CDE of mirror nuclei which is the difference between binding energy of the mirror nuclei is not constant and there is some changes with increase in excitation energy of the nuclei due to rearranging of the nucleons.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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