International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-11,November 2016
ISSN: 2395-3470
www.ijseas.com

Energy Levels Calculations of Potassium Isotopes Using OXBASH Code

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Abstract
In this paper, isotopes of Potassium (A=38-40) are calculated using shell model OXBASH code. The calculations have been done through the SD and SDPF space models, respectively. By comparing calculated energy states with the experimental values, the optimal three potential interactions which had good agreement with the experimental values were selected for these isotopes.

Keywords: *Energy Levels, Shell Model, OXBASH Code, Isotopes, Interaction Potential.*

1. Introduction

OXBASH is a powerful computer code for determining the energy levels of light and medium mass nuclei. Using this code, one can compute the energy levels of hundreds of nuclei, and validate the results by comparing them with those obtained by experiments. In addition, studying the energy levels of nuclei with shell model was always a challenge for nuclear physicists, and up to now, different models were proposed for investigating this issue. In this regard, too many computational codes were developed, and OXBASH is one of the advanced codes in this area. Studying the energy levels show that first excitation energy in some of even-even nuclei is considerably higher than the other adjacent even-even nuclei. Investigations on this subject point out that, the gaps between single-particle states for specific proton and neutron number are remarkably higher than the gaps between other states. Due to this behavior, magic numbers were suggested for nucleolus. This means that, the existence of magic proton and neutron numbers is the basis of suggesting the layer model in nuclear physics. Therefore, the goal of this paper was to compute the energies of Potassium isotopes (A=38-40***)*** using OXBASH code. OXBASH is set of programs 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. This code comes with a library of model spaces and interactions. In this paper, the OXBASH code version 2005-08 for windows was used, which can be installed and used in any PC [1].

2. Theory and Calculation

First, isotopes of Potassium as well as the basic information needed for running this code (such as atomic number, neutron number, mass number of desired Isotope, Isospin, Parity, number of valence particles, and the number of levels, in which nucleons can be excited to, are obtained by reference [1]. Considering the difference between excitation states for various Potassium isotopes, the number of levels will be also different. After running program for different models and interaction potential for each isotope, some files are obtained showing which model, and interaction potential has been used in running the program. In this way, OXBASH calculate the excitation energy of initial state, energy levels and the possibility of placing nucleons in different energy levels. When the calculated results of code agree with those of experiments [2], the potential selection is successful. Therefore, the outcomes of code are plotted and their agreements with the results of experiments are investigated.

There are many codes written for this purpose such as: Nutshell, REDSTICK, ANTOINE, etc.

In this paper we were using OXBASH code, a code which has been developed in this field for many years.

After selecting the appropriate models based on the valence nucleons, OXBASH lists the possible initial states, and then it develops the linear combination of initial states, by which the desired values for J and T are obtained. The number of linear combinations determines the size of J-T matrix. Finally, by selecting desired interaction, the Hamiltonian is formed, and then the calculations are performed. By default, 10 lowest energies are specified in the outcome.

3. SD and SDPF models space

The "model space" indicates the orbitals and the truncation within that set of orbitals which is assumed for a given calculation. Generally, the best and most complete results are obtained when the model space is as large as possible. However, the computation time increases exponentially with the size the model space, and empirical Hamiltonians are better determined in smaller models spaces. Thus the choice of model space is a compromise between what one would like to describe and what is computationally practical.
The specific distribution of valence particles over a given set of valence orbits will be called a partition. The complete or "full" model space includes all possible partitions for a given set of orbits .According to the fact that space model represents considered orbitals in the calculations, considering the number of valence nucleons of Potassium (A=38-40),the appropriate models for performing the calculations for these nucleolus are SD and SDPF models space. These models contain valence orbitals of 1d3/2, 1d5/2, 2s1/2 for SD and 1d5/2, 1d3/2, 2s1/2, 1f7/2, 1f5/2, 2p3/2, 2p1/2 for SDPF model.

4. Interaction types

The starting point for shell-model Hamiltonians is the renormalized G matrix based upon modern N-N interactions [8]. The first normalized G matrix in SD and SDPF models were proposed in the mid 1960's by Kuo and Brown , 1992 by E. K. Warburton and B. A. Brown, respectively [5], [10], [11], and its results had good agreements with the experimental values [3, 4]. When the G matrix is used to calculate the spectra for the SD-shell and SDPF- shell nuclei with more than one particles or holes, the agreement with the experimental energy spectra deteriorates rapidly as the number of particles or holes is increased [6]. There were several attempts to find improved empirical Hamiltonians. By 1976 Chung and Wildenthal [12], [8] had obtained empirical Hamiltonians for the lower-part of the SD and SDPF shells and the upper part of these shell.
In OXBASH for SD and SDPF spaces, to perform the calculations, 18 different interactions were included [1, 2]. In this paper, the calculations were done for W, KUOSD, SDBA potentials for $^{38\text{-}39}$K and SDPF40, SDPFMW, SDPFNOW for ^{40}K.

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-11,November 2016
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www.ijseas.com

Table 1: ^{38}K energy levels calculations with different potentials.

Wave function number(J)	*E(MeV) W*	*E(MeV) KUOSD)*	*E(MeV) SDBA*	*E(MeV) Experimental*
1	0.992	*0.310*	*0.000*	*1.698*
2	3.209	*2.672*	*2.854*	*3.341*
3	4.726	*4.232*	*4.600*	*4.174*
4	5.039	*4.742*	*5.032*	*5.192*
5	5.952	*5.507*	*7.180*	*5.906*
6	5.952	*5.507*	*7.180*	*5.906*
7	6.245	*5.929*	*7.991*	*6.002*
8	6.599	*6.099*	*8.569*	*7.396*
9	9.215	*6.876*	*9.343*	*8.692*
10	7.633	*7.058*	*10.343*	*8.473*

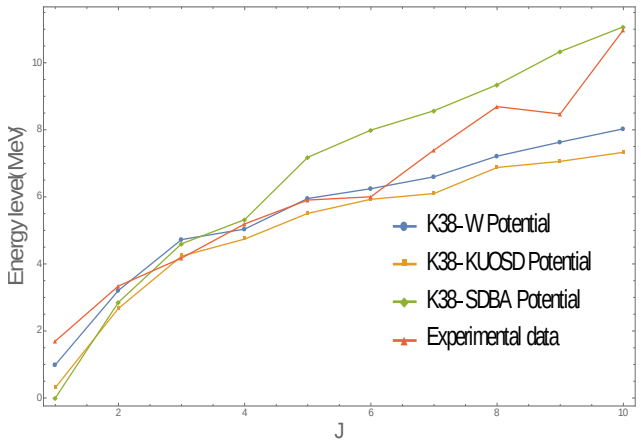

Fig 1. Resulted curves for energy levels calculations of ^{38}K isotope for different interaction potential.

Table 2: ^{39}K energy levels calculations with different potentials.

Wave function number(J)	*E(MeV) W*	*E(MeV) KUOSD)*	*E(MeV) SDBA*	*E(MeV) Experimental*
1	0.000	0.000	0.000	0.000
2	5.559	4.929	6.747	4.930
3	5.608	6.029	8.036	5.579
4	6.972	6.718	9.988	6.916
5	8.814	8.038	10.137	8.028
6	9.482	8.856	11.368	9.909
7	10.041	9.874	13.184	----
8	10.636	10.374	14.003	----
9	11.935	11.730	15.242	----
10	12.619	12.930	17.854	----

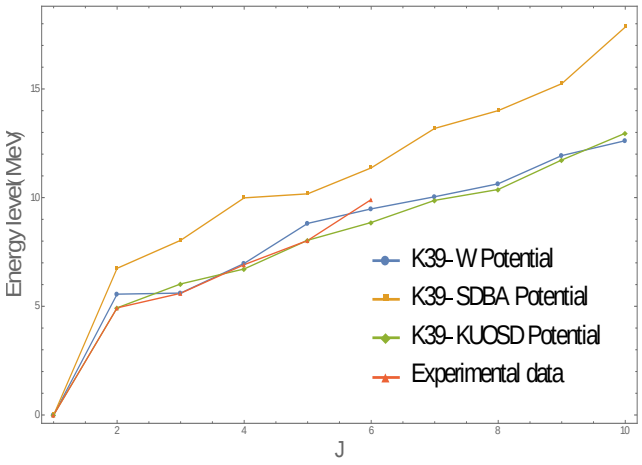

Fig 2. Resulted curves for energy levels calculations of ^{39}K isotope for different interaction potential.

Table 3: ^{40}K energy levels calculations with different potentials.

Wave function number(J)	*E(MeV) SDPF40*	*E(MeV) SDPFMW*	*E(MeV) SDPFNOW*	*E(MeV) Experimental*
1	0.000	0.000	0.000	0.000
2	7.018	5.533	3.746	3.768
3	12.255	9.781	5.361	5.077
4	13.668	11.348	6.609	6.277
5	16.438	13.145	9.765	7.472
6	16.849	13.258	10.906	----
7	17.978	14.909	12.679	----
8	20.579	17.097	13.246	----
9	21.715	18.344	13.801	----
10	23.123	19.321	15.542	----

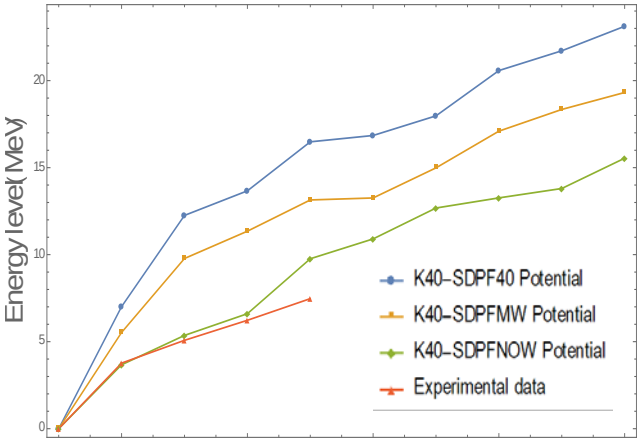

Fig 3. Resulted curves for energy levels calculations of ^{40}K isotope for different interaction potential.

By executing this code to SD model space for ^{38}K, ^{39}K and SDPF model space for ^{40}K, we obtained energy levels, and by comparing these results with experimental data we found that W and SDPFNOW interaction potentials for SD and SDBA model spaces lead to best results to experimental data. Results have been shown in figure 1, 2 and 3.

4. Conclusions

We have compared calculated results for energy levels which are obtained by running OXBASH code for 18 different interacting potentials in SD and SDPF space model for ^{38}K, ^{39}K and ^{40}K isotopes and comparing them with experimental data. As it shows, the results for W and SDPFNOW interactions overall are in good agreement with experimental data for ^{38}K, ^{39}K and ^{40}K respectively, meanwhile in some cases comparison between levels shows good fit for some other interactions.

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