# Shell Model Calculation of $^{39}$K

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## Introduction

Nucleus in the neighborhood of doubly closed $^{40}$Ca gives us a unique opportunity to investigate the interplay between single particle and collective excitations experimentally and interpret them theoretically through microscopic shell model calculation [1, 2]. $^{39}$K is an odd-even (Z=19, N=20) nucleus in this mass region. Previously this nucleus was studied by Th. Andersson et al. [3] through heavy-ion reaction. They have extended the level scheme of $^{39}$K up to 19 MeV and assigned the spin and parity of the levels from DCO measurements. However, the spins and parities of most of the levels ware not confirmed/assigned. A band like level structure has also been reported at high excitation energy. The spin and parity of these levels are not yet confirmed / assigned. They have performed shell model calculations using Sakakura-Arima-Sebe and Hsiehmooy-Wildenthal [4] (HMW) interactions to understand the origin of the excited levels in $^{39}$K. In their calculations, only $1d_{3/2}$ and $1f_{7/2}$ orbitals were considered as the valance space and the excitation energies were calculated for all possible combinations of these seven valance particles. The results are reported in ref. [3]. It has been noticed that at high spins, the calculated energies did not agree well with the experimental values. Therefore, our primary motivation is to perform shell model calculations using full *sd-fp* model space to improve the calculated energies of $^{39}$K.

## Results and Discussions

We have performed Large Basis Shell Model (LBSM) calculations using OXBASH [5] to understand the microscopic origin of these high spin states. The valance space consists of $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, $1f_{7/2}$, $1f_{5/2}$, $2p_{3/2}$, and $2p_{1/2}$ orbitals for both protons and neutrons above the $^{16}$O inert core. The number of valance particles in $^{39}$K is 23 (protons + neutrons). The "*sdpfmw*" interaction, taken from WBMD *sd-fp* shell Hamiltonian [6] is used for the calculations. For the positive parity states, 0p-0h ($3/2^+$), 2p-2h ($13/2^+$ - $21/2^+$) [Theo-P2] and 4p-4h ($23/2^+$-$27/2^+$) [Theo-P3] excitations are considered. The negative parity states are generated by exciting 1 (1p-1h) [Theo-N1] and 3 (3p-3h) [Theo-N2] particles to the *fp* shell. In our calculations, the $1d_{5/2}$ orbital was totally filled up with 12 particles only for 4p-4h excitation to overcome the dimensionality problem. For all other calculations, full *sd-fp* model space has been used.

It has been reported earlier [3] that the calculated wave function for the ground state of $^{39}$K ($3/2^+$) has a 76% 0p-0h component. In our calculation, it has 100% 0p-0h component and the calculated binding energy of $^{39}$K (-264.505 MeV) is in agreement with the experimental binding energy -264.180 MeV. Full *sd-fp* calculations also improved the energies of the $13/2^-$ and $21/2^+$ levels. In their calculations [3], these are the maximum possible angular momentum states generated from 1p-1h and 2p-2h excitations, respectively. In Fig-1, we have compared the calculated energies with the experiments. In a few cases, the order of appearance of the excited levels has been changed. As for example, the positions of the first $13/2^+$ and $15/2^+$ states have been interchanged in the theoretical results (Fig-1). These discrepancies are resolved by introducing different particle restrictions in the $1d_{5/2}$ orbital. For the prediction of spins and parities of the un-assigned levels, we have compared their energies with the calculated positive and negative parity states. The reduced transition probabilities for a few transitions have also been calculated and compared with the experimental values (Table-1). This calculation has been carried out with $e_P$=1.5e, $e_n$=0.5e and free values of g-factors. .

A detailed investigation on their calculated wave functions will be carried out to understand the microscopic structure of the high spin levels in $^{39}$K.

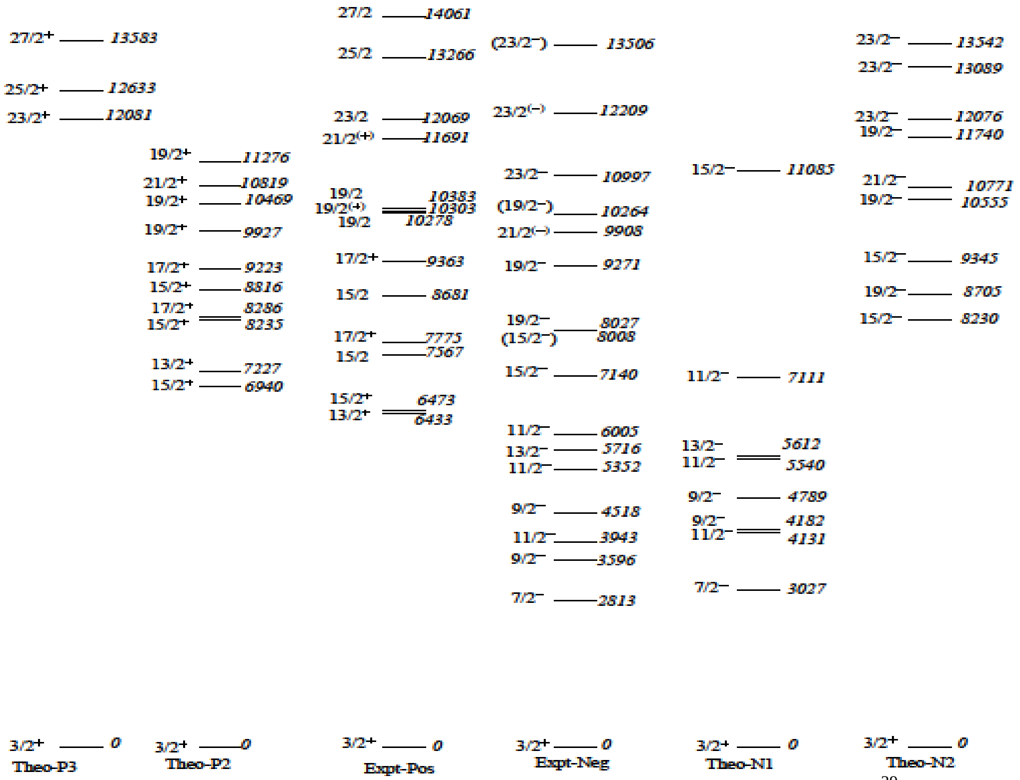


Fig-1: Comparison between experimental and theoretical level energies in $^{39}$K.

Table-1: Reduced Transition Probabilities for a few transitions in $^{39}$K

| $E_x$ keV | $\tau_m$ ps | $J_i$ | $J_f$ | $E_\gamma$ keV | B(E2) $e^2$-fm$^4$ | | B(M1)×10$^{-2}$ $\mu_N^2$ | | B(M2) $\mu_N^2$-fm$^2$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Expt. | Theo | Expt. | Theo | Expt. | Theo |
| 2813 | 61(6) | 7/2$^-$ | 3/2$^+$ | 2813 | | | | | 6.3(6) | 6.0 |
| 3597 | 55(4) | 9/2$^-$ | 7/2$^-$ | 783 | 5.6(5) | 4.4 | 0.069(6) | 0.2 | | |
| 5716 | 0.3(1) | 13/2$^-$ | 11/2$^-$ | 1774 | 10(3) | 9.9 | 3.5(9) | 4.1 | | |
| 7567 | 0.4(1) | 15/2$^+$ | 15/2$^+$ | 1094 | | | 7(2) | 4 | | |
| 7775 | 1.4(4) | 17/2$^+$ | 15/2$^+$ | 1301 | 30(14) | 37.3 | 0.5(2) | 1.0 | | |

## Acknowledgment

A.B and R.R acknowledge Prof. M. Saha Sarkar for her fruitful suggestions and encouragement. They also thanks DST-SERB (Project No. EMR/2016/006339) for providing financial support.

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