Shell closure at N=32 in Cr isotopes: A shell model study

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Introduction

One of the interesting phenomena in nuclear physics is upon going away from the valley of stability in the nuclear chart, the energy gaps between shells change, some new large gaps may appear or known ones vanish. Such phenomena of appearing a new shell gap at N=32 other than well known magic number (N=28) has been observed in in even-even Cr isotopes while studying the experimentally obtained systematics of first excited state energy, $E^{2_1^+}$ and $E^{4_1^+}/E^{2_1^+}$ ratio [1, 2]. In neighbourhood, for Ti isotopes also same feature has been observed due to enlarged shell gap between $1f_{7/2}$ and $2p_{3/2}$ neutron orbitals [2, 3]. An effort has been made in the present manuscript to emulate the same effect in Cr through large scale shell model (LSSM) calculation.

Methodology

The LSSM calculations were performed for Cr isotopes from N=22 to 34 using M-scheme based KSHELL code [4, 5] which utilises thick-restart block Lanczos method to obtain the low lying eigen values/energy levels and corresponding wave functions. A minimally modified version of the Kuo-Brown G matrix (KB3) was used as effective Hamiltonian [6] with 514 two-body matrix elements. The ^{40}Ca was used as core and $1f_{7/2}$, $2p_{3/2}$, $1f_{5/2}$ and $2p_{1/2}$ orbitals as model space for both protons and neutrons, with single particle energies as 0, 2, 6.5 and 4 MeV respectively.
The calculations were performed using the FUJITSU workstation at IUAC having Intel Xeon processor with clock speed 2.40 GHz and 64GB RAM. This machine has 20 cores (10x2) and a 1TB storage.

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N	$\mathbf{E^{2_1^+}}$ (exp)	$\mathbf{E^{2_1^+}}$ (SM)	$\mathbf{E^{4_1^+}/E^{2_1^+}}$ (exp)	$\mathbf{E^{4_1^+}/E^{2_1^+}}$ (SM)
22	892	993	2.23	1.90
24	752	806	2.47	2.26
26	784	845	2.40	2.35
28	1434	1665	1.65	1.62
30	835	964	2.18	2.14
32	1007	1213	2.06	1.92
34	881	963	2.20	2.16

TABLE I: Comparison of experimental & SM calculated first excited state energy, $E^{2_1^+}$ (in keV) and $E^{4_1^+}/E^{2_1^+}$ ratio for even-even Cr isotopes.

Results & Discussion

The experimental and shell model (SM) computed first excited states energy, $E^{2_1^+}$ are in good agreement with the experimental results. The difference in energy values is ≈ 100 keV except for N=32 with ≈ 200 keV difference. They are mentioned in Table I along with $E^{4_1^+}/E^{2_1^+}$ ratio. The $E^{2_1^+}$ energy have maxima at N=28 & N=32 indicating the large shell gap can be seen in Fig. 1. Also the ratio of $E^{4_1^+}/E^{2_1^+}$ plotted in Fig. 2 matches well with experimental data and having minima at same neutron numbers.
The trends for experimental and SM calculations are similar for both systematics, thus SM calculations are able to reproduce the large shell gap between $1f_{7/2}$, $2p_{3/2}$ neutron orbitals in Cr isotopes as observed in the experimental data on the basis of $E^{2_1^+}$ & $E^{4_1^+}/E^{2_1^+}$ ratio systematics.

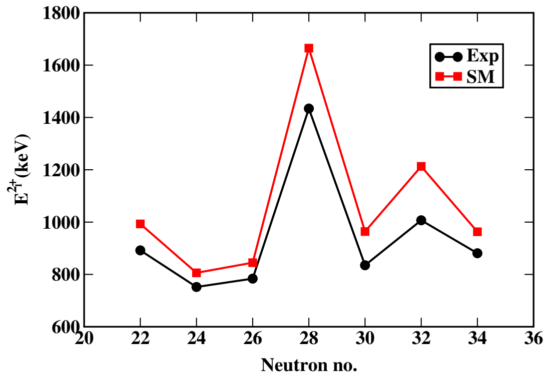

FIG. 1: Comparison of experimental and SM obtained first excited state energy, $E^{2^+_1}$ for Cr isotopes with Neutron number.

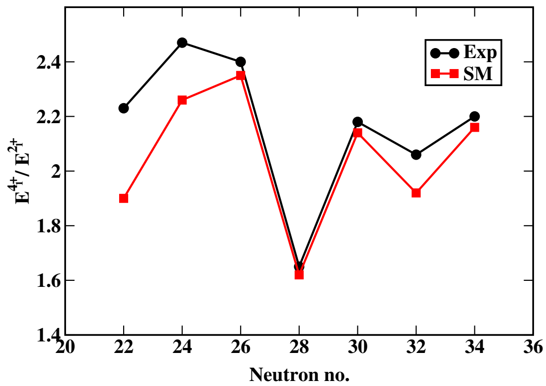

FIG. 2: Comparison of experimental and SM obtained $E^{4^+_1}/E^{2^+_1}$ ratio for Cr isotopes with Neutron number.

Conclusions

The experimental and SM calculations results matches very well for $E^{2^+_1}$ & $E^{4^+_1}/E^{2^+_1}$ ratio systematics for Cr isotopes. The maxima in $E^{2^+_1}$ and minima in $E^{4^+_1}/E^{2^+_1}$ ratio systematics are able to predict the enlarged shell gap at neutron number 28 and 32.

Acknowledgments

The authors are thankful to HPC group, IUAC for providing a computing facility to perform LSSM calculations. Thanks are due to Dr. U. S. Ghosh, IUAC and Mr. Chandra Kumar, IUAC for fruitful discussion about shell model calculations.

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