High spin states in ^{88,89}Zr

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I. INTRODUCTION

The high spin states of an atomic nucleus with proton and neutron numbers near the shell closure is a topic of current interest. The limited available valence space for excitation at high spin provides stringent test for the available interactions. The shell model interactions are not yet optimized in the model space spanning $f_{5/2}$, $p_{3/2}$, $p_{1/2}$ and $g_{9/2}$ orbital (f_5pg_9). The high spin states of nuclei close to ^{90}Zr provides perfect testing ground for the available interactions. With this motivation, high spin states of $^{88,89}Zr$ have been populated with ^{13}C beam at 60 and 50 MeV, from TIFR-BARC Pelletron accelerator facility, bombarded on a ^{80}Se target. The γ-rays decaying from the residual nuclei were observed at the Indian National Gamma Array (INGA) consist of 18 clover detectors coupled to a 100 MHz digital data acquisition system (DDAQ). The data was sorted into γ-γ matrix and γ-γ-γ cube and the level scheme was developed based on intensity and coincidence relationship. The advantage of the clover geometry and the availability of detectors at various angles was used for polarization and angular distribution measurements. The lifetime of some of the states were measured using prompt-delayed coincidence analysis and Doppler shifted attenuation method. In our work, the level scheme of ^{88,89}Zr was extended with addition of a number of new γ-rays and excited states. The spin and parity of a number of levels have been modified and several known γ-rays are rearranged. The experimental data have been compared with the large scale shell model calculations. The f_5pg_9 model space has been used for the calculations, with inert ^{56}Ni core. Two interactions, namely, JUN45 [1] and jj44b [2] have been used for the shell model calculation with unrestricted f_5pg_9 model space. Both these interactions were developed starting from realistic Bonn C interaction. However, these interactions were fitted over two different sets of nuclei resulting in different two body matrix elements and single particle energies. Both shell model calculations show good agreement with the observed excited states of ^{88,89}Zr. The remarkable agreement of theory at low spin of ^{88}Zr has excluded the possibility of a vibration mode of excitation to be coupled with the low spin states of the nucleus, as predicted in a previous literature [3]. Instead, our work has suggested that ignoring the particle excitation from the $p_{3/2}$ and $f_{5/2}$ orbitals is the possible reason of previous discrepancies with theory. This work has also highlighted the need of full model space calculation without any restriction in particle excitation to study the nuclei close to ^{90}Zr. Further, calculations have suggested that in ^{88}Zr, the configuration mixing is reduced in the high spin positive parity states than the low spins. The reduced configuration mixing is also indicative from experimental observation of first and second non-yrast excited states at high spin. The ground state has been correctly reproduced from both the interactions. The JUN45 interaction has shown better overall agreement with experimental levels of both the isotopes. Probably, the difference between the results of the two interactions is due to the difference in sets of nuclei which were used to fit the interactions. As mentioned in reference [1], the JUN45 interaction was constructed with data from different nuclei in the model space, while carefully avoiding the Ni and Cu isotopes. Whereas, the Ni and Cu isotopes data

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were used in the fitting of jj44b interaction. Recent measurements on the excited states of the Ni and Cu isotopes have provided evidence of excitation from the $f_{7/2}$ orbital. As a result, the TBME's and the single particle energies of jj44b interaction might have the effect of soft-Ni core contribution. Whereas, in Zr isotopes, with $Z = 40$ sub-shell closure, the robustness of the 28 shell gap might be preventing any contributions from the Ni core excitation. Hence, the JUN45 provides better agreement to the experimental results of Zr, as the interaction is not affected by the softness of Ni core in Ni and Cu isotopes. Conversely, in ^{88,89}Zr excitation from the Ni core have not been observed resulting in good agreement of the JUN45 interaction. A regular dipole band, with fast M1 transitions has been observed in ^{89}Zr. The shell model calculations using both interactions have been found to be progressively overestimating the experimental levels of the band. Evidently, this implies that the model space for shell model calculation is inadequate to describe the excited states of the band. Further, at an excitation energy $\lesssim 6$ MeV particle excitation across the shell closure could be possible. Moreover, the constant moment of inertia of the band indicates a collective multi-quasi-particle excitation. Regular band structures observed in doubly closed nuclei like, ^{56}Ni and ^{40}Ca have been interpreted in terms of multiple particle-hole excitations across major shell gap. The ^{89}Zr being close to $N = 50$ shell closure and $Z = 40$ sub shell closure makes it a probable candidate for cross shell excitations. Further at high angular momentum, the Coriolis and centrifugal forces can play a significant role in driving the high-j orbitals to come down in energies and becoming accessible for particle excitations. A cranked Nilsson Strutinsky model calculation has been performed which explains the regular band in ^{89}Zr using a configuration with 3 protons aligned in $g_{9/2}$ and 1 neutron excited to $d_{5/2}/g_{7/2}$ orbitals. Similar cross shell excitation mode has also been searched in ^{88}Zr. For this purpose, a heavier ^{30}Si projectile was bombarded upon ^{65}Cu target and a grazing angular momentum of $\sim 60\ \hbar$ has been pumped into the compound system. Both thick target and Doppler corrected thin target experiments were performed. However, in case of ^{88}Zr the maximum angular momentum state observed has not been beyond $\sim$22 $\hbar$. Similar, situation has been recently observed in ^{88}Y [4] where, even after an angular momentum of 40 $\hbar$ was imparted into the compound system the maximum angular momentum reported was only 19 $\hbar$. The possible reason for not observing higher angular momentum states can be presence of a long-lived isomer, which is restricting the decay of transitions from the states above. Further, there could also be possibility of presence of deformed structure which is decaying to the yrast levels in highly fragmented decay paths. Due to high fragmentation the intensity of the transitions could be very weak to observe. The third possibility could be that, at this energy particle decay modes are predominant hindering γ-decay channels. Hence, the study of high spin states in ^{88}Zr have posed an interesting question regarding the possibility of highly deformed structure at high spin and the role of cross shell excitations in this regard.

The results of my thesis work have opened up the scope of further studies both in experimental and theoretical aspects. More experiments for the lifetime measurement of all the levels of the ^{88,89}Zr are required for the stringent test of the shell model interactions.

References

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