Exotic structures in nuclei – following the experimental fingerprints at the stable shell gaps

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The nuclear shell gaps play the most important role in understanding the evolution of nuclear structure with the change in proton and neutron numbers. The inter-relation of nuclear shapes and their co-existence to the nuclear shell gaps will be discussed in the light of some of the recent experimental progress in the studies of exotic structures in nuclei.
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Introduction

The shell structure in nuclei was established long back through the pioneering works of Mayer and Jensen [1,2]. This provided almost complete understanding of the extra stability of spherical magic nuclei. After almost a decade from the work of Mayer and Jensen, Bohr and Mottelson showed that a deformed nucleus can generate excitation through rotation [3], similar to that of a di-atomic molecule. It was also understood that the quadrupole deformed nuclei become extra stable, compared to the near spherical ones, for some specific proton and neutron numbers, in between the spherical magic shell gaps [4].

Towards the end of the twentieth century, experimental fingerprints were obtained [5] which provided the understanding that spherical shell gaps may get modified as one move away from the line of β-stability [6]. Since then, the studies of nuclei that are exotic in N/Z became extremely important in understanding the modification of nuclear density distribution and the consequent spin orbit interaction. Very recently, it has been proposed that the nucleonic shell gaps can even be stronger than the spherical shell gaps [7,8]. This owes to the four fold degeneracy (exotic symmetry breaking) of the nucleonic levels attained through tetrahedral deformation of the nuclear surface (like a pyramid). Till today, efforts are underway for experimental discovery of the nuclear structure attained with this exotic symmetry breaking.

The role of the shell gaps in the evolution of exotic nuclear structure has, therefore, been one of the most intriguing phenomena and the experimental research on nuclear structure has evolved around these shell gaps. The experimental fingerprints of exotic nuclear structures as a function of the evolution of nuclear shell gaps will be discussed in the light of some unique experiments that are being carried out at VECC, Kolkata. The three major areas of research in this line are outlined in the following sections.

Spherical shell gap at Z = 50, N = 82

The validity of spherical magic numbers was based on the nuclei lying on the β-stability line. However, with the advent of radioactive ion beams, the neutron rich nuclei have been accessible, giving rise to the opportunity to explore the validity of nuclear shell model away from the β-stability line. In recent times, the region around ^{132}Sn (Z = 50, N = 82) has seen lots of interesting findings that provided the opportunity to explore the doubly shell closed behavior in the heaviest neutron rich nuclei. The nuclei lying at the north of ^{132}Sn can be experimentally accessed through fission and the transition strengths and transition moments in these nuclei have been of extreme importance in understanding the shell closed behavior at Z = 50 and N = 82. The results obtained in this region; from the gamma-gamma fast timing activities at VECC, Kolkata, viz. Ref. [9-10] & others; will be discussed in the light of other recent results.

Deformed (quadrupole) shell gap at N = 90

The shell gap at N = 90 plays an important role in the co-existence of different orders of shapes and quantum shape phase transition. The presence of multiple 0^+ levels in the even-even nuclei around N = 90 carry the fingerprints of shape coexistence. The critical point for the quantum shape phase transition can be explored with the determination of E0 transition rates from these 0^+ levels. The scarcity of data for the E0 transition rates for the 0_3^+ levels around N = 90 and its importance in understanding the shape phase transition will be discussed along with the recent findings in this mass region, obtained from gamma-gamma fast timing activity at VECC, Kolkata, viz., Ref. [11] & others.

Deformed (tetrahedral) shell gap at Z = 64/70 and N = 90

The consequence to the formation of shell gaps with tetrahedral deformation of nuclear surface has been found only as a theoretical proposition, till date. It has been found that such shell gaps exist throughout the periodic table, however, the ones accessible with stable targets and projectiles lie in the region around Z = 64/70 and N = 90. The experimental fingerprints for the associated rotational symmetry breaking are known to be complex and the corresponding rotational band is expected with no/very weak E2 transitions. In addition, the tetrahedral symmetry breaking gives rise to a band structure that is intermingled with that from an octahedral symmetry breaking, the former being the sub(symmetry)group of the latter one. The spectroscopic criteria for finding such rotational sequences have been established [12] consequent to multiple failures in finding the experimental fingerprint. The details will be discussed in the light of the recent efforts in experimentally searching the tetrahedral band structures in ^{152}Sm (Z = 62 and N = 90) using an array of 12 Clover HPGe detectors coupled to a digital DAQ facility, set up at VECC, Kolkata, in collaboration with SINP and UGC-DAE-CSR, Kolkata.

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