Open problems in Nuclear Level Density

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Introduction

The nuclear level density (NLD) is a fundamental property of atomic nucleus, which defined as the number of nuclear level per unit excitation energy. This is an important physical quantity used in the statistical calculation of compound nuclear decay and therefore, useful for both basic and applied research. The general behaviour of the NLD with excitation energy(E_X) is $e^{\sqrt{a*E_X}}$, a is the level density parameter related to the single particle level density parameter at Fermi energy [1, 2].The variation of the NLD with the number of nucleons (N, Z and A), angular momentum, parity, isospin, shell effect and paring have been studied both experimentally and theoretically for over many decades. The recent development of the state of the art experimental techniques, namely CERN n-TOF experiment through neutron resonance spectroscopy, Oslo method for study of continuum gamma rays in coincidence with the particles in transfer induced reactions, Mumbai method for the study of continuum particle spectra in coincidence with the particles (ejectiles) in the breakup-fusion reaction, provide opportunities to study many important problems pertaining to the level density. The recent progress in the measurements highlighting various aspects mainly on shell effect, collective enhancement and pairing reentrance in the nuclear level density and future perspectives will be discussed.

Shell effects on the NLD and its damping with E_X

The shell effect is expected to wash out with excitation energy so that a approaches its liquid drop value at $E_X \geq 40$ MeV [3] and subsequent parametric form invoking shell correction [4] is used in the statistical model calculation. The shell effect and its damping over wide excitation energies have been deduced from an exclusive measurement of the neutron time of flight spectra with a large area ($\sim$1m^2) neutron detector array [5] in the ^{7}Li breakup followed by fusion of triton with ^{205}Tl. A controlled measurement was also made with ^{nat}Ta where the shell effect of the residual nucleus is small($\sim$2 MeV). The allowed values of the physical parameters, γ which relates the damping of the nuclear shell effect and the asymptotic nuclear level density parameter$\tilde{a}$, have been obtained for the first time in the Pb region [6]. The value of γ controlling the damping of the shell effect found to be $(0.060^{+.010}_{-.020})$ MeV^{-1}. The value of shell damping factor is relevant for the nuclear astrophysics and also for the synthesis of supper heavy nucleus. The measurement on nuclear shell effect can be extended to other doubly closed shell nucleus (^{132}Sn) and the nuclei where the shell effect is sizable ($\sim$10-13 MeV, Bi and Po isotopes).

Rotational enhancement of the NLD

The occurrence of collective rotational motion in nuclei implies an increase in the number of level due to contribution of low energy rotational levels and thereby a significant increase in the total NLD [2] than for the spherical nuclei. The collective enhancement is the ratio of level density of deformed nucleus to those for the spherical nucleus at given E_X. The enhancement factor varies with excitation energy [7] and is expected to wash out with excitation energy. The experimental observation on the washing out of collective enhancement is limited [8] and it is therefore necessary to measure the damping factor over wide range of

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excitation energy and nuclei with mass numbers (A=160-190, 230-250). An experimental program has been initiated at the Mumbai PLF to address the damping of rotational enhancement in the nuclei A$\sim$160 and the critical energy where this effect is washed out. An exclusive measurement of neutron spectra was measured from ^{161}Dy incoincidence with alpha particles in the breakup fusion reaction as measured in ref [6]. The experiment was performed at the PLF by using a 27 MeV pulsed ^{7}Li beam on self-supporting ^{159}Tb foils (thickness 3 mg/cm^2. Alpha particles were detected at backward angles ($\pm 150^\circ$) in two Si-strip telescopes(16 channels each, 50μm thick ΔE and 1.5mm thick E detector) and the neutrons were measured using an array of 15 liquid scintillator (each 12.7 cm diameter and 5 cm long cylindrical shape coupled to 12.7 cm diameter PMT) placed at flight path of 70 cm with respect to target. The statistical analysis of neutron spectra can shed light on the rotational enhancement of the nuclear level density and its damping with excitation energy.

Pairing reentrance in the NLD

The pairing in atomic nuclei plays an important role in the study of the nuclear structure at low energy and its effect is also observed in the nuclear level density. Recent, microscopic shell model Monte Carlo (SMMC) calculation for N=40 isotones (^{68}Ni, ^{70}Zn, ^{72}Ge and ^{80}Zr nuclei) showed the phenomenon of pairing reentrance in rotating hot nucleus through an anomalous behavior of specific heat and also in the level density [9, 10]. Bardeen-Cooper-Schrieffer (BCS)-based quasiparticle calculation including quasi-particle number fluctuation plus the non-collective rotation for ^{60}Ni, ^{72}Ge nuclei also showed the pairing reentrance in the heat capacity and rather weak signature in level density [11]. A possible explanation to the observed unusual structure in the proton spectra in ^{104}Pd is the enhancement of nuclear level density at low excitation energy and high angular momentum [12]. This observation reconcile with the pairing reentrance at high frequencies similarly that predicted by SMMC calculation. The enhancement in the extracted NLD at low excitation energy and high angular momentum in ^{104}Pd demonstrates the pairing reentrance in the level density and also corroborated with the calculation within the framework of the finite temperature BCS theory(FTBCS) [13]. Many such measurements are required in the open shell nuclei at finite temperature and high angular momentum where the both pairing and rotation plays crucial role for describing the pairing reentrance which manifested through specific heat and level density.

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