Study of nuclear level density using light particle evaporation as a probe

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Introduction

An accurate determination of nuclear level density (NLD) is essential for quantitative description of several important physical phenomena like particle evaporation, fission, multifragmentation, spallation *etc*. Moreover, the knowledge of NLD (ρ = dN/dE) is of fundamental interest as it can provide interesting tests of different microscopic approaches of nuclear structure commonly used to calculate level densities. NLD is a characteristic property of every nucleus and it is expected to vary grossly exponentially with excitation energy. However, the exact nature of variation of NLD critically depends on various factors like angular momentum, deformation, shell correction, parity and isospin. Theoretically, the simplest and most frequently used analytic expression for NLD [$\rho(E)\sim exp2\sqrt{(aE)}$] is obtained under the framework of Fermi-gas (FG) model. In the FG description of NLD the most important factor is the level density parameter (*a*) which is directly related to the density of single-particle states around the Fermi energy. It may be noted that the simplest FG description of NLD does not incorporate important nuclear properties such as pairing, shell and collective effects. These effects can be incorporated in a phenomenological manner through a number of adjustable parameters (either in ρ or in *a*). On the experimental side, information on the variation of NLD can be obtained by studying the evaporation spectra of light particles emitted from an equilibrated compound nuclear source. The aim of the present studies is to improve and extend experimental information on the dependence of NLD on key nuclear factors and try to resolve some of the open questions (will be discussed in detail during the presentation) in these areas. We particularly focus on the angular momentum and excitation energy dependence of the level density parameter (LDP) from the measurement of particle evaporation spectra for a number of nuclei in different nuclear mass regions.

Experimental Detail

A series of experiments have been carried out using the ^{4}He ion beam of several incident energies between 28–60 MeV from the K130 cyclotron at VECC. Kinetic energy spectra of light charged particles and/or neutrons emitted from a number compound nuclei have measured at backward angles. The multiplicity of low energy γ-rays has also been measured to estimate the populated angular momenta. A 3-element detector telescope [Si-Strip, Si-Strip, CsI(Tl)], a number of liquid scintillator based neutron detectors and a 50-element BaF_2 detector array were used to detect the charged particles, neutrons and γ-rays, respectively.

Results and discussions

A. Angular momentum dependence of NLD

Angular momentum (spin) dependence of NLD has been studied by simultaneously measuring kinetic energy spectra of the evaporated neutrons, protons, and α-particles at backward angles in coincidence with the multiplicity of low energy γ-rays in case of the ^{4}He + ^{58}Ni, ^{93}Nb and ^{115}In reactions at $E^*\sim35$ MeV. Different angular momentum regions in the residual nuclei were selected experimentally by measuring the γ-ray fold distributions using the BaF_2 detector array. The experimental kinetic energy spectra of neutron, proton and α-particles were measured for different folds where a high fold event corresponds to a high *J* populated in the final nucleus. The analysis of γ-ray fold gated particle spectra have been carried out using the statistical model code CASCADE. The spin dependence of NLD was incorporated through the spin and deformation dependent rotational energy. It is observed that the shapes of the fold gated particle spectra could not be explained by the standard level density formulation; so additional spin dependence was suggested which was reflected through the variation of the level density parameter with angular momentum. From the present analysis, it is observed that the inverse level density parameter ($k = A/\tilde{a}$) decreases significantly with the increase in <*J*> (Fig.1) for all three emissions. The observed variation of *k* (or *a*) with angular momentum is in contrast with the existing picture where the level density parameter is not expected to vary explicitly with spin or deformation. The decrease of *k* at higher *J* is indicative of the fact that there is a relative increase of NLD at higher angular momentum. Shape change at higher angular momentum based on RLDM as well as the concept of collective enhancement as per the existing formulations have failed to explain the observed variation of NLD with *J*. Detail microscopic calculations for the specific systems will be useful to understand the phenomena in more detail.

B. Temperature dependence of the level density parameter

The LDP is known to exhibit interesting variation with excitation energy (temperature). The excitation energy dependence of *a* is highly sensitive to the shell structure of atomic nuclei (particularly at low excitations). A strong departure of the level density parameter from its standard low energy value of ~*A*/8 is very well known for nuclei in the vicinity of closed shells. However, the shell effects are strongly excitation energy dependent, expected to be damped and finally washed out at higher excitation energies. Consequently, at high excitation, the level density parameter reaches an asymptotic value ($\tilde{a}$), which varies smoothly with mass number. There has been a number of recent investigations that generated renewed interest in investigating the excitation energy (*U*) or temperature (*T*) dependence of the level density parameter. We have performed a number of experiments using ^{4}He-ion beams from the K130 cyclotron at VECC in order to look for the energy (temperature) dependence of the level density parameter. The nuclei investigated can be categories into two groups (1) spherical or near spherical nuclei (^{201}Tl*, ^{212}Po*, ^{213}At*) and (2) nuclei having large ground state deformations (^{169}Tm*, ^{173}Lu*, ^{185}Re*). It is observed that the general trend of the experimental data for both the groups can reasonably be described by the relationship $\boldsymbol{k(U)=k_0+\kappa(U/A)}$ [Fig.2]. The value of κ which determines the rate of increase of *k* with *U* was found to be strongly dependent on the mass number (*A*).

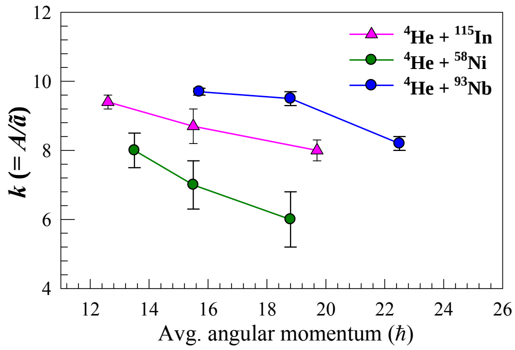

Fig. 1 Variation of the inverse LDP as a function of angular momentum for the three reactions as obtained from the analysis of neutron evaporation spectra.

Although the gross variation of *k* with *U* matches the energy systematic interesting fluctuations of the extracted *k*-values and the measured temperatures were observed at *U* ~25 MeV in case of nuclei having large ground state deformations. This could be connected with the fadeout of collective enhancement in NLD where the level density is expected to exhibit a kink or a plateau as function of excitation energy.

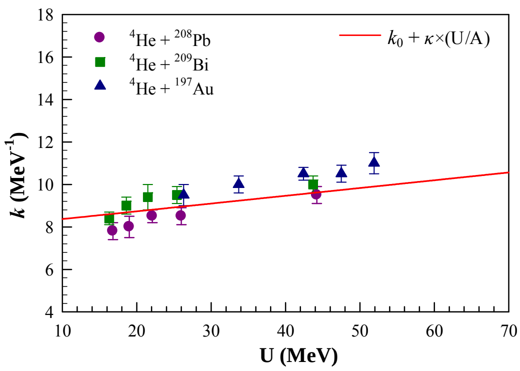

Fig. 2 Excitation energy dependence of the inverse level density parameter for the three near spherical systems.

The temperature dependence of *a* has also been investigated and compared with the Thomas-Fermi model calculations. It is observed that the temperature dependence of *a* can mainly be accounted by the temperature dependence of the effective mass (m^*) of the nucleons inside the nucleus. The detail experimental investigations and important results will be presented in detail during the symposium.