Study of shell effect in nuclear level density in $^{4}He + ^{208}Pb$, ^{209}Bi reactions

Pratap Roy*, K. Banerjee, C. Bhattacharya, R. Pandey, A. Sen, S. Manna, S. Kundu, T. K. Rana, T. K. Ghosh, G. Mukherjee, A. K. Saha, J. K. Meena, R. M. Saha, J. K. Sahoo, A. Dhal, A. Dey, S. Mukhopadhyay, Deepak Pandit and S. Bhattacharya#

Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata - 700064, INDIA
* *email: roypratap@vecc.gov.in*
 # Raja Ramanna Fellow at VECC

Introduction

Nuclear level density (NLD) which is the most important input to the statistical models of various nuclear reactions has been a matter of investigation over a long time. Understanding the exact nature of variation of NLD with various nuclear factors such as excitation energy, angular momentum, pairing and shell corrections, deformation, isospin, parity etc. is crucial from both fundamental and application point of view. In some of our recent studies, important information regarding the dependence of NLD on angular momentum [1-3] and ground-state deformation [4] have been extracted. Another very important factor, by which NLD is strongly influenced, is the shell structure of atomic nuclei. Shell effects are strongly excitation energy dependent, expected to be gradually damped and finally washed out at higher excitation energies. In most of the phenomenological descriptions of NLD, shell effect is incorporated by using an excitation energy (U) dependent parameterization of the level density parameter (a) [5] given by,

$$a(U) = \tilde{a}\ [1+ \Delta S/U\ (\exp\text{-}\gamma U)] \ \ldots\ldots\ldots\ldots (1)$$

Here $\tilde{a}$ is the asymptotic value of the level density parameter at high excitation energy. This procedure is quite useful as it is easy to handle and is applicable for almost all the nuclei in the entire nuclear chart. However, experimental data on the variation of NLD over wide excitation energy range (particularly at lower energies) for nuclei having large ground-state shell correction (ΔS) are a few. In one of such studies the shell damping factor (γ) was measured experimentally for the first time in the ^{208}Pb region very recently [6]. On the other hand, in another interesting theoretical study on the energy dependence of the level density parameter it has been shown that the variations of the level density parameter with excitation energy can't always be reproduced with the simple analytic expression like Eqn.1, and the effect of proton shell and neutron shell should be accounted separately (*i.e.* $\gamma_P \neq \gamma_N$) [7]. In view of the above scenario it will be interesting to extend similar studies near the doubly magic ^{208}Pb region for different systems. Experimental information on the variation of shell effect in NLD can be obtained by measuring particle evaporation spectra from excited compound nuclei in a wide excitation energy range. However populating low excitation energies (where shell effects are significant) in the fusion reactions are difficult due to the entrance channel Coulomb barrier. One solution to this problem can be the use of light ion beams such as *p* or *α*-particles for which the Coulomb barriers are relatively small. So with the aim to study the role of shell structure in NLD and its excitation energy dependence, we have carried out a new experiment, in which neutron evaporation spectra have been measured from two different compound nuclei ^{212}Po and ^{213}At populated through the reactions

$$^{4}He + ^{208}Pb \rightarrow ^{212}Po^{*}\ (Q_{CN} = -8.95\ MeV)$$
$$^{4}He + ^{209}Bi \rightarrow ^{213}At^{*}\ (Q_{CN} = -9.25\ MeV)$$

in an excitation range $E^{*} \sim 20 - 30$ MeV. The choice of the current reactions was particularly useful to produce low excitations as both the reactions have large negative Q-values (~ –9 MeV). The current systems having large ground-state shell correction values (ΔS ~ 9 – 10 MeV) is expected to reveal important information on the shell effects in NLD.

Experimental Detail

The experiment was carried out using the ^{4}He ion beam of three incident energies 31, 35 and 40 MeV from the K130 cyclotron at VECC. In the experiment two self-supporting foils of ^{208}Pb

(enriched) and ^{209}Bi were used as targets. The emitted neutrons were detected using four liquid scintillator detectors placed at the laboratory angles of 90^0, 105^0, 120^0 and 150^0, at a distance of 1.5 m from the target. Energies of the emitted neutrons were measured by the time of flight (TOF) technique, where the start of the TOF was taken from a 50 element BaF_2 γ-ray detector array placed very close to the target. The neutron and γ separation was achieved by both the TOF and pulse shape measurements. To reduce the contribution of background neutrons coming from the beam dump, it was kept at a distance of ~3 m from the target position and was shielded well with layers of lead and paraffin. The excitation energy dependent efficiency, which is a very crucial parameter, was measured in the in-beam condition using a standard ^{252}Cf neutron source.

Results and discussions

The extracted neutron kinetic energy spectra at different angles were converted to the centre of mass frame and found to be almost overlapping (particularly with E_n <8 MeV); indicating that they have originated from an equilibrated compound nuclei. Both the compound nuclei (^{212}Po and ^{213}At) were populated at sufficiently low excitation energies where shell effects are expected to play important role. Also the measurement has been carried out at three different excitations to see the variation of the statistical model parameters with energy (if any). At the lowest excitation energy both the compound nuclei ^{212}Po* and ^{213}At* decay predominately through *1n* and *2n* channel populating ^{211,210}Po and ^{212,211}At respectively. The measured neutron spectra were compared with the statistical model calculations carried out using the CASCADE code [8] and are shown in Fig.1 and Fig.2. The excitation energy dependence of the level density parameter was taken through the Reisdorf approach [9], where the shell correction in *a* was incorporated by an expression similar to Eqn.1. The experimental spectra (in the neutron energy range 2–7 MeV) were fitted by varying the inverse level density parameter *k (A/ã)*. From the preliminary analysis it is observed that the experimental spectra for the ^{4}He + ^{208}Pb and ^{4}He + ^{209}Bi reactions were fitted with an average inverse level density parameter $k \approx 8.5$ (±0.5) and 9.0 (±0.5) respectively. The damping of the shell effect is well represented by a damping factor [10],

$$\gamma^{-1} = (0.4\times A^{4/3})/\tilde{a} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

for both the systems at all three energies. The detailed analysis and understanding of the current data is in progress and its implications will be presented during the conference.

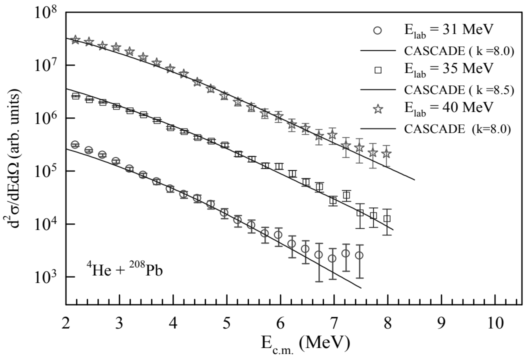

Fig. 1 Measured neutron energy spectra (symbols) alongwith statistical model fits (solid lines) at different excitation energies in case of the ^{4}He + ^{208}Pb reaction.

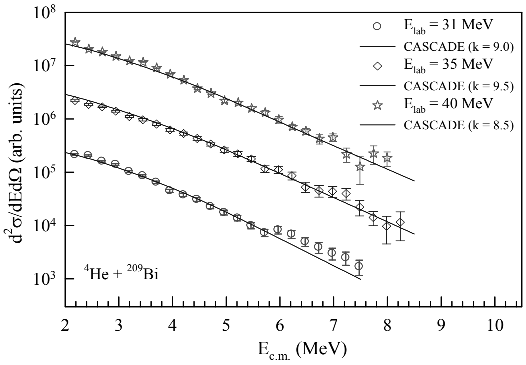

Fig. 2 Same as Fig.1 for the ^{4}He + ^{209}Bi reaction.

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