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Angular momentum dependence of the nuclear level density parameter

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Abstract. Neutron evaporation spectra alongwith γ-multiplicity has been measured from the ^{185}Re* compound nucleus at the excitation energies ~27 and 37 MeV. Statistical model analysis of the experimental data has been carried out to extract the value of the inverse level density parameter *k* at different angular momentum regions (*J*) corresponding to different γ-multiplicity. It is observed that, for the present system the value of *k* remains almost constant for different *J*. The present results on the angular momentum dependence of the nuclear level density (NLD) parameter $\tilde{a}$ (=*A/k*), for nuclei with *A* ~180 is quite different from our earlier measurements in case of light and medium mass systems. The present analysis provides useful information to understand the angular momentum dependence of NLD at different nuclear mass regions.

1 Introduction

Nuclear level density (NLD) [1] is one of the most important inputs in the theoretical models used to calculate the cross sections of various nuclear processes like particle evaporation, fission and multifragmentation. Moreover knowledge of NLD can provide an interesting test of different microscopic approaches of nuclear structure used to calculate level densities. It is thus important to understand the dependence of NLD on the key nuclear parameters like excitation energy (temperature), angular momentum (spin), isospin and deformation. In recent years a number of studies have been carried out to understand the angular momentum (*J*) dependence of nuclear level density both theoretically and experimentally. In a couple of recent experiments [2, 3], angular momentum dependences of NLD were studied by analyzing the *α*-particle evaporation spectra emitted from various compound systems. In one of these experiments with *A*~ 180, E^*~ 56–59 MeV, and <*J*> ~15–30 ħ, the inverse level density parameter *k* was found to remain constant within the statistical errors in the measured angular momentum range [2]. In the other experiment performed at *A* ~120, E^* ~ 60 MeV and *J* ~ 10–20 ħ, no systematic variation of inverse level density parameter was observed [3]. For Z_R = 49, 50, and 51 (Z_R is the atomic number of the evaporation residue) *k* was found to be constant while for the other cases it was observed to increase with increasing angular momentum. On the other hand theoretical calculations for similar systems showed that the inverse level density parameters should increase for all the cases [4]. On contrary, in a measurement of angular momentum gated neutron evaporation spectra for *A* ~ 118, E^* ~ 31 MeV and 43 MeV and *J* ~ 10–20 ħ, we have

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observed that the inverse level density parameter (k) decreases with increasing angular momentum [5]. In another recent study, in order to understand the variation of the level density parameter with angular momentum in a more systematic manner we have simultaneously measured all (major) the light-particle (n, p, and α) evaporation spectra along with the γ -ray multiplicity in ^{4}He on ^{93}Nb (^{97}Tc*) and ^{4}He on ^{58}Ni (^{62}Zn*) reactions at the incident energy of 35 MeV [6]. In this study a systematic trend of decrease of inverse level density parameter with the increase in angular momentum (J~ 10-20 $\hbar$) has been observed from the study of all three evaporation spectra, for both systems. It will be interesting to extend this kind of study for relatively heavy systems. In this paper we report our new measurement on angular momentum gated neutron evaporation spectra for the ^{4}He + ^{181}Ta (^{185}Re*) reaction at two excitation energies E^{*}~37 and 27 MeV.

2 Experiment and Results

The experiment was performed using 40 MeV ^{4}He ion beam from the VECC K-130 cyclotron accelerator facility. A self-supporting foil of ^{181}Ta (thickness ~1 mg/cm^{2}) was used as target. The compound nucleus ^{185}Re* was populated by the complete fusion reaction at an excitation energy ~37 MeV. To detect the emitted neutrons, four liquid-scintillator (BC501A) detectors, each covering a solid angle ~ 5.6 mSr, were placed outside the scattering chamber at angles 92^{0}, 107^{0}, 121^{0} and 151^{0} with respect to the beam direction at a distance of 150 cm from the target. Energy of the emitted neutrons has been measured using the Time of Flight (TOF) technique whereas the neutron gamma discrimination was achieved by both pulse shape discrimination (PSD) and time of flight. The efficiency correction for the neutron detectors were performed using Monte Carlo Computer code NEFF [7]. In the present experiment, populated angular momenta were recorded by measuring the γ-multiplicity using a 50 element BaF_2 based low energy γ-ray filter array. Data from the neutron detector were recorded in event by event mode alongwith the γ- multiplicity. The fold-gated neutron energy spectra were measured to study the angular momentum dependency of NLD. Here fold is defined as the number of BaF_2 detectors firing simultaneously in an event, which is directly related to the compound nucleus angular momentum. The angular momentum distributions for different folds were obtained by converting the measured γ-fold distribution, using the Monte Carlo simulation technique based on GEANT3 toolkit [8]. The theoretical neutron energy spectra were calculated using the statistical model code CASCADE [9], with the extracted angular momentum distributions for different folds as the input.

The experimental neutron energy spectra for ^{4}He + ^{181}Ta system, along-with the corresponding CASCADE fits have been shown in Fig.1.

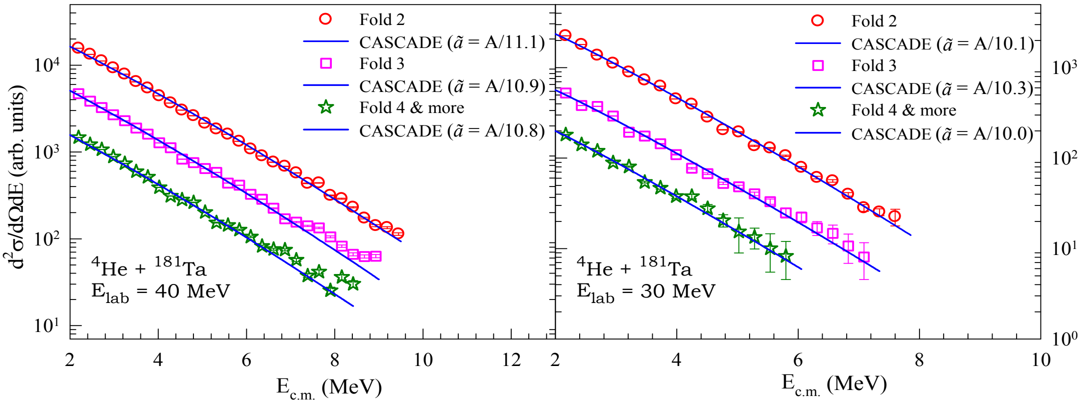

Figure 1. Experimental neutron evaporation spectra for the ^{4}He + ^{181}Ta reaction along with the CASCADE predictions at different folds.

In the CASCADE calculation, the phenomenological level density formula predicted by the back shifted Fermi gas model was used. The shapes of the neutron energy spectra are mostly sensitive to the level density parameter. As the variation in other statistical model parameters was insignificant, their default values were taken in the calculation. The value of the level density parameter is usually estimated as $\tilde{a} = A/k$, where k is called the inverse level density parameter. The optimum values of k were extracted by fitting the experimental neutron spectra using the χ^2 minimization technique. The extracted values of the inverse level density parameter as obtained for different average angular momenta corresponding to different γ-folds are shown in Fig. 2.

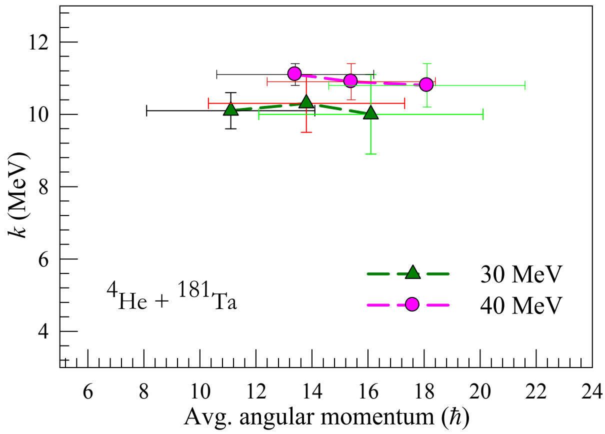

Figure 2. Variation of the inverse level density parameter with angular momentum for the ^{4}He + ^{181}Ta reaction at incident energies of 30 (circle) and 40 (triangle) MeV.

It can be observed from Fig. 2 that the values of the inverse level density parameter remains unchanged (within the statistical errors) for all the folds (angular momentum). The constant nature of k (or $\tilde{a}$) with the variation in J is observed at both the excitation energies.

Table 1. Variation of the inverse level density parameter (k) at different folds as observed in different reactions in the similar excitation energy and angular momentum range.

System	Compound nucleus	Ref.	E_{lab} (MeV)	Fitted inverse level density parameter (k) vales in MeV		
				Fold 2	Fold 3	Fold ≥4
^{4}He + ^{181}Ta	^{185}Re*	Present work	40	11.1 ± 0.3	10.9 ± 0.5	10.8 ± 0.6
			30	10.1 ± 0.5	10.3 ± 0.8	10.0 ± 1.1
^{4}He + ^{115}In	^{119}Sb*	Ref. [5]	42	11.1 ± 0.3	9.5 ± 0.5	8.9 ± 0.5
			30	9.4 ± 0.2	8.7 ± 0.3	8.0 ± 0.5
^{4}He + ^{93}Nb	^{97}Tc*	Ref. [6]	35	9.7 ± 0.1	9.5 ± 0.2	8.2 ± 0.2
^{4}He + ^{58}Ni	^{62}Zn*	Ref. [6]	35	8.0 ± 0.5	7.0 ± 0.7	6.0 ± 0.8

A comparison of the extracted values of the inverse level density parameter at different folds for ^{4}He induced reactions on different targets, populating compound nuclei around similar excitation energy and angular momentum range have been shown in table 1. It can be observed from the table that for the light and medium mass systems (^{62}Zn, ^{97}Tc and ^{119}Sb) there is a substantial decrease in the k value

at higher folds (angular momentum). On the contrary the *k* value remains almost same at all the folds in the case of the relatively heavy system (^{185}Re). It is therefore interesting to note that, for light and medium mass nuclei (^{119}Sb, ^{62}Zn and ^{97}Tc) measured neutron evaporation spectra in coincidence with γ- ray multiplicity give clear signature of angular momentum dependence of nuclear level density. On the other hand for heavy mass system (^{185}Re) no such dependence on angular momentum has been observed. The constant nature of the level density parameter with the variation in angular momentum in the 180 mass region has also been observed by Gupta *et. al,* from the measurement of the α-particle evaporation spectra. However a strong dependence of *k* on *J* was observed from similar measurement in A~120 mass region by the same group.
The present result as well as the earlier measurements as discussed above indicates that angular momentum dependence of NLD is sensitive to mass number. However to understand the angular momentum dependence of NLD and its sensitivity over the mass number comprehensively more exclusive measurements at different mass region is required.

3 Summary and Conclusion

The energy spectra of the neutrons emitted in the decay of ^{185}Re* have been measured at backward angles in coincidence with the γ-ray multiplicity. The analysis of γ -ray fold-gated neutron spectra have been carried out using the statistical model code CASCADE. From the present data it is observed that the *k* value remains almost constant with the increase in angular momentum. The present observation is in contrast to the earlier observed trend from similar measurement for the light and medium mass systems. The different trend of variation of *k* with *J* observed in different mass region indicates a sensitivity of angular momentum dependence of NLD on mass number.

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