Light particle evaporation in ^{16}O, ^{20}Ne + ^{56}Fe, ^{58}Ni reactions

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Introduction

Study of evaporation spectra of light particles (e.g., *n*, *p*, and α-particles) emitted in heavy-ion fusion-evaporation reactions provide useful information in understanding the properties of nuclear level density (NLD) at high excitation energy and angular momentum. The NLD defined by the total number of states accessible in a given nucleus at a given excitation energy serves as a crucial input to the statistical model (SM) calculations of nuclear reaction cross-section. Moreover, knowledge of NLD is of fundamental interest as it provides information on the statistical and thermodynamic properties of nuclei.

For a spherical nucleus of mass number *A* at moderate excitation energy E^* and spin *J*, the intrinsic level density, $\rho_{\rm int}(E^*,J)$, is generally evaluated using the simple analytical expression based on the Fermi gas (FG) model as follows [1]:

$$\rho_{\rm int}(E^*,J) \cong \frac{\pi}{\sqrt{12}} \frac{\exp(2\sqrt{aE^*})}{a^{1/4}E^{5/4}} \exp\left(-\frac{(J+1/2)^2}{2\sigma^2}\right)$$

In the Fermi gas description, the level density is mainly determined by the value of the level density parameter *a* which is directly related to the density of single-particle states near the Fermi energy. In the FG picture, the calculated value of *a* comes out to be around A/15 where A is the nuclear mass number. However, the estimated value is about two times lower than the experimentally observed value of *a* at low energies (A/8). It should be remembered at this point that the Fermi gas approximation is a very crude description of the atomic nucleus which can be much more complicated in reality. Thus the value of *a* may not be a constant quantity and may exhibit interesting variation as a function of E^*, and *J*. It is further influenced by the shell structure, and shape of the nucleus. There are several experimental studies that suggest that the value of *a* reduces at higher temperatures and approaches the Fermi gas limit (A/15) [2-6]. In recent years, we have carried out several investigations on the variation of *a* on E^* and *J* using light-ion induced reactions that allowed us to populate the nuclei in a temperature range of T ~ 0.5 – 1.5 MeV and angular momentum range of *J* ~ 10 – 20 ħ [7-10]. With the availability of heavy-ion beams at the K130 cyclotron at VECC, it has been possible to populate nuclei with much higher temperatures and spins. In the present work we have measured proton, and α-particle evaporation spectra in ^{16}O, and ^{20}Ne induced reactions on ^{56}Fe, and ^{58}Ni targets. Kinetic energy spectra of the light charged particles have been measured at various laboratory angles. The present study will help us in understanding the behavior of nuclear level density at high energy and angular momentum. It will also be possible to understand the interplay between the equilibrium and non-equilibrium particle emissions processes.

Experimental details

The experiment has been carried out using the ^{16}O and ^{20}Ne ion beams of different incident energies from the K130 cyclotron at VECC. In the experiment, self-supporting foils of ^{58}Ni (~0.4 mg/cm^2) and ^{56}Fe (~0.4 mg/cm^2) were used as targets. The compound nuclei ^{74}Kr* (^{16}O + ^{58}Ni), ^{76}Kr* (^{20}Ne + ^{56}Fe), and ^{72}Se* (^{16}O + ^{56}Fe) have been populated in the excitation range of E^*~110 – 130 MeV. The light charged particles (*p*, and α-particles) emitted during the compound nuclear evaporation process were detected using a ΔE-E telescope consisting of a 100 μm Si surface barrier detector (ΔE), and a 6 cm CsI(Tl) detector (E). The kinetic energy spectra of proton and α-particles were measured at various laboratory angles between 15^0 –120^0. Energy calibration for the Si detector was performed using standard ^{229}Th α-particle source. The CsI(Tl) detectors were calibrated (separately for proton and α-particles) using the ΔE -E_R correlation plot, where ΔE is the energy lost in the Si detectors and E_R is the remaining energy that is deposited in CsI(Tl). The ΔE values were calculated using the calibrations of the Si-detectors, and the E_R values corresponding to a given ΔE were estimated from the energy loss calculation performed using the SRIM software [11]. The following table shows the details of the different reactions studied in the present work.

Projectile	Target	CN	E_{lab}	E^*
^{16}O	^{56}Fe	^{72}Se	161	127.77
^{16}O	^{58}Ni	^{74}Kr	161	123.55
^{16}O	^{58}Ni	^{74}Kr	144	110.23
^{20}Ne	^{56}Fe	^{76}Kr	166	123.68
^{20}Ne	^{56}Fe	^{76}Kr	148	110.27

Results and discussions

The preliminary analysis of part of data has been carried out. The proton, and α-particle spectra in case of the $^{16}O + ^{56}Fe$ and $^{16}O + ^{58}Ni$ reactions at E_{lab} = 161 MeV at different laboratory angles have been extracted and converted to the centre-of-mass frame. The spectra measured at the most backward angle (120^0) were compared with the statistical model calculation carried out using PACE4 [12]. The high energy part of the spectra (10 – 30 MeV for proton, and 20 – 50 MeV for α-particles) have been fitted with the SM calculation by varying the inverse level density parameter (k = A/a). The experimental spectra alongwith the SM fits have been displayed in Fig.1. It is observed that the experimental spectra can reasonably be explained by the PACE4 calculation using the k values in the range of 12 – 13 MeV. The extracted k values are higher compared to the commonly accepted value of $k \approx 8$ at low energies and suggest strong energy or temperature dependence of the level density parameter. The average experimental temperature (T_{av}) have been extracted by fitting the measured spectra with a Maxwellian function $\sqrt{E}\times exp(-E/T_{av})$ and found to be ~ 4.5 MeV for the present systems. The fitted k values at high temperature are in good agreement with the theoretical calculations of Shlomo and Natowitz [13] for similar systems.

The detailed analysis and understanding of the experimental data is in progress. It is expected that the current investigation will provide useful information on the nature of NLD at high energies. The final results and its physics implications will be presented during the conference.

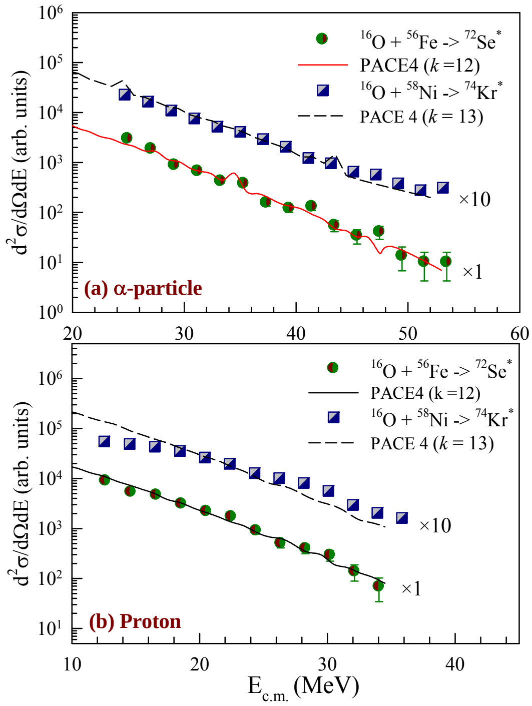

Fig. 1 Measured (a) α-particle and (b) proton spectra (symbols) alongwith statistical model fits (solid lines) in case of the $^{16}O + ^{58}Ni, ^{56}Fe$ reactions at the incident energy of 161 MeV. The spectra have been scaled for better visualization.

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