Light Particle Emission in Fusion Reactions at High Excitation Energy and Angular Momentum

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Introduction

Heavy-ion reactions at low energies ($E_{Lab} \leq$ 4-7 MeV per nucleon) and low mass region ($A\approx100$) are dominated by compound nucleus formation followed by evaporation of light charged particles and neutrons. Several recent experimental studies [1-3] reported that the light charged particles and n-spectra from mass symmetric projectile-target systems show significant deviations from predicted conventional statistical model evaporation spectra. In general, it is also accepted that at high excitation energy, fusion hindrance do take place due to dynamical effects, fusion and fission time scales are altered by such effects. The analysis of vast amount of data obtained from the measurements of pre-scission neutron multiplicity, GDR gamma ray and evaporation residue clearly suggest that the time scale for fission process is hindered due to dynamical effects such as nuclear viscosity [5]. Such hindrance can also take place for the fusion of the medium mass nuclei. In some of the analysis of the alpha, proton and neutron spectra [2,4] it was found that statistical model calculations performed using the $\boldsymbol{l}$-distribution (or $\boldsymbol{l}_{\text{graz}}$) obtained by Bass-systematics under-predicts the alpha and proton spectra and over-predicts the neutron spectra obtained through the fusion of mass symmetric entrance channel. However, these spectra were explained by using the $\boldsymbol{l}_{\text{crit}}$ value obtained from HICOL dynamical model calculations. The dynamical model predicted $\boldsymbol{l}_{\text{crit}}$ was found to be much less compared to the $\boldsymbol{l}_{\text{graz}}$ obtained through Bass- systematics. It was conjectured that, in case of mass symmetric systems, some of the higher partial waves are not fused due to fusion hindrance. In all the above measurements simultaneous analysis of all the observables, like fusion cross sections, spin distributions, evaporation residue(ER) gated proton, neutron and alpha spectra were never carried out. In order to address above problems in a better way, we have chosen a system with symmetric target projectile combination and measured simultaneously the ER cross-sections and the ER-gated proton, alpha and neutron spectrum. We report here the analysis of neutron, proton and alpha spectrum obtained from ^{28}Si+ ^{45}Sc system.

Experiment

Experiment was carried at IUAC New Delhi using Heavy Ion reaction analyzer (HIRA). ^{28}Si beam of 125 MeV was bombarded on a ^{45}Sc target of thickness 600 μg/cm^2. ERs were separated from beam like particles and detected in the focal plane detectors of the Heavy Ion reaction analyzer (HIRA). ERs were also measured at different angle settings of the HIRA to take into account the recoil due to alpha particle emission. Charged particle spectra were obtained at 40^o laboratory angle using a ΔE-E (25μm-5mm) Si surface barrier detector telescope. Calibration of telescope detector was done using 5.486 MeV α particles from ^{241}Am source. Neutron spectrum was measured at 90^o with respect to beam using a NE213 liquid Scintillator detector. Gamma and neutrons were separated both by time of flight and also with pulse shape discriminator technique. One Si surface barrier detector was also placed at 25^o to monitor beam. The trigger of data acquisition was generated by Logical OR of charged particles, neutrons and ERs.

Results and Discussion

Inclusive alpha, proton and neutron spectra were obtained from the respective detectors and separate exclusive spectra were also obtained by gating with the ER from the focal plane detector of HIRA. Figure 1 shows the both exclusive and inclusive spectra for alpha, proton and neutron.

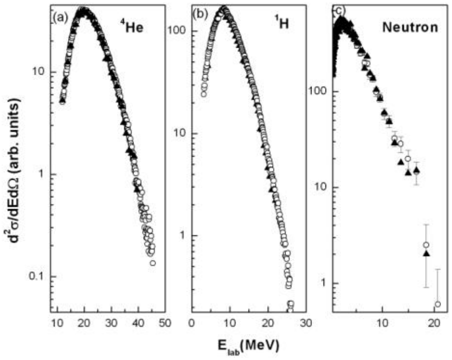

Figure 1: Comparison of the inclusive and exclusive experimental spectra of a) α-particles, b) protons and c) neutrons. The up triangles represent the ER coincidence data, and circles represent the data without coincidence.

Experimental spectra were compared with theoretical calculations using standard statistical model. In order to fit experimental data, expression for rotational energy was modified as

$$E_I = \frac{\hbar^2}{2}\frac{I(I+1)}{I_o(1+\delta_1 I^2+\delta_2 I^4)}$$

Where E_I is effective rotational energy, I is spin of nucleus, I_o rigid body moment of inertia of spherical nucleus with radius parameter *r_0=1.25 fm*, δ_1 and δ_2 are input parameters providing a range of choice for spin dependence of level density. It has been found that quantities δ_1 and δ_2 produce a noticeable change in the slope of the high energy tail of evaporation spectrum, but not in the peak. The experimental spectra were not in agreement with the theoretical calculations using rotating liquid drop model value of moment of inertia corresponding to $\delta_1=0.22*10^{-4}$ and $\delta_2=0.26*10^{-7}$ (Dashed line). A higher values of $\delta_1=0.52*10^{-4}$and $\delta_2 = 0.6*10^{-7}$ were used to explain experimental α spectra (Solid line). However it was not possible to fit proton spectra even with higher values of δ_1 and δ_2. Interestingly it was also found that neutron spectrum was also not reproduced by the statistical model calculations for reasonable values of level density parameter (a = A/8 or A/10) as shown in Figure 2.

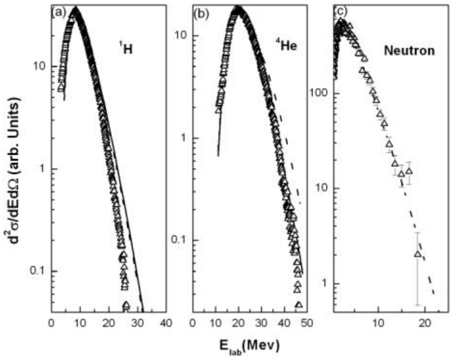

Figure 2: Comparison of the exclusive experimental data (Up triangles) with the statistical model calculations (dashed and solid lines) (a) the proton spectrum, (b) the α-spectrum and (c) the neutron spectrum.

It was found that the theoretical alpha proton and neutron spectra are not in agreement with the inclusive and exclusive experimental data. Thus we concluded that the statistical model calculation, using rotating drop liquid model and optical model transmission coefficient failed to explain the experimental data for the ^{28}Si+^{45}Sc reaction. It will be interesting to perform systematic dynamical model calculations for all the observables for the above system and some of the systems available in the literature. Such calculations and analysis are in progress.

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