Entrance channel effect on the production of high-energy γ rays

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Introduction

The γ rays emitted in nuclear reactions provide a clean probe to explore the properties of atomic nucleus and collision dynamics. The production mechanism of high-energy γ rays in nuclear reactions has, therefore, been the subject of intense investigation both theoretically and experimentally [1-3]. In heavy-ion reactions, with projectile energies below 7 MeV/nucleon, the γ-ray yield can well be understood by compound nuclear mechanism, with a γ-ray strength function dominated by the giant dipole resonance (GDR). At higher beam energies, non-statistical processes such as nucleon-nucleon bremsstrahlung contribute. The nucleon induced reactions, on the other hand, show some interesting features in the γ-ray spectrum. The nucleon can be captured to any of the single particle configurations of the composite system thereby emitting a γ ray. This is called direct capture. The nucleon can also be captured to a compound nuclear state which subsequently decays by the emission of γ rays in competition with particle decay. In between the compound and direct capture process, the γ rays can be produced by the semidirect process where the incoming nucleon excites the GDR in a single-step process, which subsequently decays by the emission of high-energy γ rays.

In this work, we present the measurement of high-energy γ-rays (5-25 MeV) for proton and alpha induced reaction on ^{115}In and ^{112}Sn nuclei, respectively. The target projectile combination was so chosen to have the nuclei of the same mass and the projectile energies were selected so that roughly the same intrinsic excitation energy is reached through the compound process. The γ-ray and neutron energy spectra both were measured. From the neutron spectra, it has been shown that level density of the nucleus away from the β-stability line decreases [4]. In this work, the results for the measured γ-ray spectra are presented.

Experimental Details

The experiments were performed at the Variable Energy Cyclotron Centre, Kolkata. The ^{1}H and ^{4}He beams of energies 12 and 28 MeV were bombarded on self-supporting ^{115}In and ^{112}Sn targets, respectively. The high-energy γ rays were measured using a part of the LAMBDA array [5] consisting of 49 large (3.5×3.5×35 cm^3) BaF$_2$ scintillators. The array was placed at a distance of 50 cm from the target position at an angle of 90° with respect to the beam direction in a 7×7 matrix. The neutrons were rejected by using the TOF technique. The start trigger was generated using two-part multiplicity filter [6]. Each part had 25 small (3.5×3.5×5 cm^3) BaF$_2$ detectors, and was placed on the top and bottom of the target chamber in 5×5 staggered castle type geometry. The data in LAMBDA array was detected in coincidence with at least one detector of the multiplicity filter. The high-energy γ-ray spectra were generated in the offline analysis by cluster summing technique [5] using proper cuts to eliminate the neutron and pile-up events. The cosmic muon events were rejected by using the hit-patterns in the LAMBDA array, which are quite different from actual γ events.

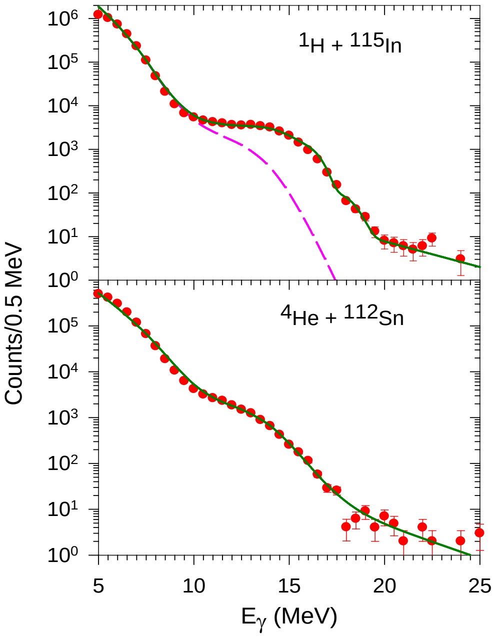

Fig. 1: Measured and calculated γ-ray spectra for the systems mentioned.

Data analysis and inferences

It is observed from the upper panel of Fig. 1 that the yield of γ rays above 10 MeV in ^{1}H + ^{115}In reaction is substantially large when compared with the statistical model calculations performed using the Hauser-Feshbach formalism (pink long-dashed line) within the TALYS code [7]. This points towards contribution from reaction channels other than the compound channel. As pointed out earlier, in nucleon induced reaction, the direct-semidirect processes play important role. The overlap between the entrance channel and the 1p-1h configurations in ^{116}Sn nucleus enhances the yield above 10 MeV. To explain the extra yield of high-energy γ-rays, we have estimated the pre-equilibrium γ-ray cross section using the TALYS code. Within TALYS the pre-equilibrium γ-ray contribution is calculated in a statistical approach using the exciton model formalism of Akkermans and Gruppelaar [8] which provides a powerful tool to model the direct-semidirect processes. It can be observed (green line, upper panel) that after adding the pre-equilibrium γ-ray cross section with that obtained with the Hauser-Feshbach approach, the data for ^{1}H + ^{115}In systems could be explained quite well. Above 20 MeV, there is some contribution from the n-n bremsstrahlung process. On the other hand, it is observed that for ^{4}He + ^{112}Sn system, the γ-ray spectrum could well be explained with statistical model calculations with a γ-ray strength function including the GDR, along with a bremsstrahlung component. It is interesting to note that the level density, used to explain the γ-ray spectrum for ^{1}H + ^{115}In system, can explain the γ-ray spectrum of the ^{4}He + ^{112}Sn system, but with an extra strength of ~ 50% of the Thomas-Reiche-Kuhn (TRK) sum rule. However, when a reduced level density was used as shown in Ref. [4] from the analysis of neutron spectra, the data could be well explained with the dipole strength given by the TRK sum rule.

In summary, we have measured the high-energy γ-ray spectra for ^{1}H + ^{115}In and ^{4}He + ^{112}Sn reactions. The ^{1}H + ^{115}In reaction shows a large yield from the direct-semidirect processes which could be explained well with the exciton model calculations, whereas the later reaction proceeds through two-step compound nuclear process. The present work corroborates the earlier result that the level density of the nuclei away from the β-stability line decreases.

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