Role of photon strength function models in describing high-energy γ-ray spectra

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Introduction

The high-energy γ rays (5-30 MeV) produced during nuclear collisions provide a clean probe to study the reaction dynamics and properties of hot and rotating atomic nuclei. Depending on the target-projectile combination and relative kinetic energy, the γ rays are produced by two-step compound nuclear mechanism, direct and semidirect capture, nucleon-nucleon bremsstrahlung process etc. The γ rays produced by compound nuclear process are theoretically corroborated by the statistical model calculations. One of the key ingredients of the statistical model calculations involving γ rays is photon strength function (PSF) by which the average electromagnetic property of excited nucleus is described. In a model-independent way, the γ-ray strength function is defined as $f_{xL}(E_\gamma) = E_\gamma^{-(2L+1)}\langle\Gamma_{xL}\rangle/D$, where $\langle\Gamma_{xL}\rangle$ and D are the average partial γ-decay width and level spacing, respectively. X and L represent type (X ≡ E/M ≡ electric/magnetic) and multipolarity of the transition, respectively. The PSF is related to the γ-ray transmission coefficient by $T_{xL}(E_\gamma) = 2\pi\, f_{xL}(E_\gamma)\, E_\gamma^{(2L+1)}$ and the photoabsorption cross section by $\sigma_{xL}(E_\gamma) = (2L+1)(\pi\hbar c)^2 f_{xL}(E_\gamma)E_\gamma^{(2L-1)}$. For medium and heavy nuclei, the E1 plays the most dominant role, whereas, for light nuclei M1 and E2 strengths have some contribution along with the dominant E1 strength.

The E1 strength is dominated by the giant dipole resonance (GDR), which exhaust most of the dipole strength. It is generally parameterized by a simple Lorentzian photoabsorption cross section which, along with the Brink-Axel hypothesis, leads to electric dipole strength function given by

$$f_1(E_\gamma) = \frac{1}{3(\pi\hbar c)^2}\frac{\sigma_0 E_\gamma \Gamma_g^2}{(E_\gamma^2 - E_g^2)^2 + E_\gamma^2\Gamma_g^2}$$

where σ_0, E_g and Γ_g are the maximum value of the photoabsorption cross section, the peak energy and the width of the GDR. It is observed [1,2] that below the peak of the GDR, the strength function obtained from the simple Lorentzian overestimates the experimental values. To account for this, different models for the PSF have been proposed such as the generalized Lorentzian form by Kopecky and Uhl [2], the hybrid model by Goriely [3]. These models are based on the work of Kadmenskij *et. al,* developed using the Fermi liquid theory of finite systems [4]. The main features of these models are a nonzero limit of $f_1(E_\gamma)$ as $E_\gamma \rightarrow 0$ along with an energy dependent damping width which depends also on the temperature of the state at which gamma transition takes place. It was observed that calculations of the neutron capture reactions substantially depend on the choice of the photon strength functions [2,3] thereby affecting the yield of the elements produced by r-process [3].

The strength function derived from the simple Lorentzian is generally used to describe the high-energy γ-ray spectrum generated from the decay of excited nuclei. The aim of the present work is to compare the role on the different PSFs in describing the high-energy γ-ray spectra for nuclei in different mass region. In this paper the results from the preliminary analysis of the γ-ray spectrum of ^{62}Zn is presented.

Experimental details

The experiment was performed at the Variable Energy Cyclotron Centre, Kolkata using 28 MeV ^{4}He beams from the K-130 cyclotron on a self-supporting ^{58}Ni target. The compound nucleus ^{62}Zn was populated at 29.6 MeV excitation energy. The high-energy γ rays were measured, in coincidence with low-energy multiplicity gamma rays, by using a part of the LAMBDA array [5] consisting of 49 large (3.5×3.5×35 cm^3) BaF_2 scintillators. The low-energy γ-ray multiplicities were measured by using the multiplicity filter [6]. The neutrons were rejected by using the TOF technique and the pile-up events were rejected by pulse shape discrimination methods. 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 events were rejected by using the hit-patterns in the LAMBDA array, which are quite different from actual γ events.

Results and discussions

Statistical model calculations were performed within the Hauser-Feshbach formalism by using the TALYS-1.95 reaction code [7]. The angular momentum distribution of the compound nuclear cross section was simulated from the measured low-energy γ-ray multiplicity distribution, and was incorporated in the TALYS code. The response function of the LAMBDA array was folded with the γ-ray spectrum calculated by using the TALYS code before comparing with the experimental data. In Fig. 1 the measured high-energy γ-ray spectrum is shown along with the results of the statistical model calculations where all parameters were the same except for the models of PSF. It is interesting that the PSF derived using a simple Lorentzian reproduce the data fairly well in the entire region compared to other two models of the PSF calculated using the same GDR parameters (lower panel of Fig. 1). It was also observed the M1 strength, which is parameterized as a simple Lorentzian in the TALYS code, also plays a crucial rule in the calculations. However, it should be stressed that these are preliminary results. The detailed analysis is in progress and will be presented during the symposium.

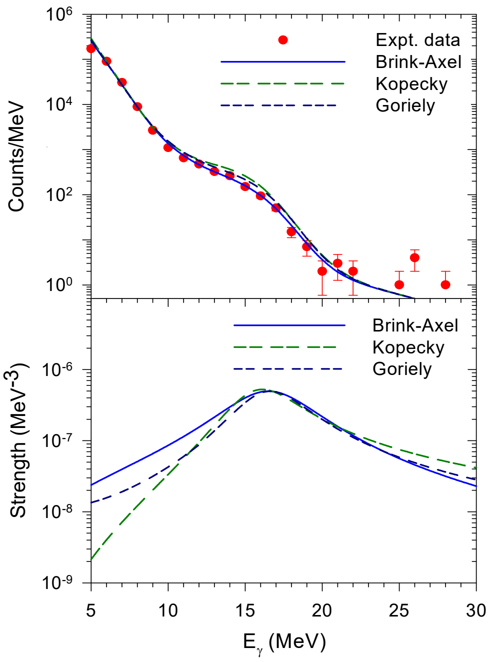

Fig. 1. Experimental high-energy γ-ray spectrum along with the results of the statistical model calculations (upper panel). Different PSF models incorporated in the calculations (lower panel).

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