Photon strength functions from (p,γ) reactions

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Abstract. The ^{50}Cr(p,γ)^{51}Mn proton capture reaction has been used to study the photon strength functions by utilizing primary gamma ray transitions from the entry states to discrete states of known spins and parities. The reaction was conducted with the 3 MV Tandetron accelerator at iThemba LABS which delivered proton beams of 2.5 to 2.740, 2.760 to 3.0 MeV and 3.675 to 4.498 MeV in intervals of 20-25 keV with beam currents of up to 5 μA. In this work the proton capture reaction was employed together with the Average Resonance Capture method to extract the shape of the PSF of ^{51}Mn.

1. Introduction

The photon strength function (PSF) is a statistical nuclear property and provides information about the electromagnetic properties of atomic nuclei [1]. Information on statistical properties like the PSF can be useful to constrain capture cross section through the Hauser-Feshbach formalism, if the corresponding nuclear level density is known. There are several ways in which PSFs can be measured, however special attention is given to the shape method [2] which has been shown to reproduce the slope of the PSF in charged-particle nuclear reactions. The method does not rely on the s-wave neutron resonance spacing (D_0) to obtain the shape of the PSF.

2. The shape method

The shape method is extensively described in Ref. [2] as a novel and mostly model independent technique used to establish the slope of nuclear level densities (NLDs) and PSFs. The method, when applied to Average Resonance Capture (ARC) spectra obtained with proton beams, makes use of primary gamma ray transitions with energy E_γ decaying from initial excitation energy regions E_i with energy loss ΔE of 15-20 keV and feeding final discrete levels L_i with energy E_f. From the ARC spectra pairs of primary gamma ray transitions feeding discrete states having the same J$^\pi$ with different level energies are used to demonstrate this method. Since the pairs are collected from different ARC spectra which cover different excitation energy regions they are therefore scaled with respect to each other and sewed together to obtain the shape of the

PSF. The PSF will be measured using intensities of primary gamma ray transitions N_{L_j} from the same initial excitation energy region to levels with the same J^π. Therefore the cross section $\sum_{J^\pi} \sigma_{J^\pi}(E_i)$ is identical for all the intensities. Assuming that statistical gamma ray decays from the quasi-continuum are dominated by dipole transitions [3] means that we only have to perform E_γ^3 [2, 3] corrections on the intensities of the primary gamma ray transitions to obtain the shape and therefore the energy dependence of the PSF as shown in Figure 1.

3. Experimental details

The experiment was performed at iThemba LABS where the 3 MV Tandetron accelerator was used to accelerate proton beams of 2.5-2.740, 2.760-3.0 and 3.675-4.5 MeV bombarding ^{50}Cr targets of 200-350 μg/cm^2 thicknesses in intervals of 20-25 keV. These intervals are equivalent to the energy lost in a target and make it possible to populate 7.771-8.011, 8.031-8.271 and 8.946-9.771 MeV excitation energy regions of interest. The targets had a high isotopic purity of 96% and were on a 1 mg/cm^2 gold backing. The beam current throughout the experiment ranged from 0.5 to 5 μA. The emitted gamma rays from the ^{50}Cr(p,γ)^{51}Mn proton capture reaction were detected using a spectrometer consisting of a Compton-suppressed segmented clover detector positioned at 90° with respect to the beam line. The clover detector consists of four segmented coaxial HPGe crystals housed in a bismuth germanate (BGO) Compton suppression shield. The energy calibration of the HPGe clover detector at high energy regions of the spectrum was achieved by using an Americium-Beryllium neutron source which when it interacts with iron emits gamma rays with energies up to the 9 MeV region. The source was suitable for this experiment since the reaction of interest produced gamma rays close to 10 MeV. Efficiency corrections were performed on the primary gamma ray intensities using NPTool simulated absolute photopeak efficiency.

4. Results

A total of 64 beam energies were measured in intervals providing 64 high energy gamma ray spectra yielding different excitation energy regions. These spectra contain well-resolved primary gamma ray transitions that decay to low-lying states. The spectra collected from different proton energies and populated at different excitation energy regions are shifted along the energy axis with respect to a reference spectrum until the primary gamma ray to the ground state of these spectra coincided with that of the reference spectrum. The spectra are then combined and summed up (ARC method) [4] into bins of 260, 260 and 825 keV for the 2.5-2.740, 2.760-3.0 and 3.675-4.5 MeV proton beam energies, respectively. The summed primary gamma ray spectra for the 2.760-3 MeV proton beam range is shown in Figure 2. Similar spectra for the 2.5-2.740 and 3.675-4.5 MeV proton beam energies were also constructed. The intensities of the efficiency corrected primary gamma ray transitions to individual states of the same J^π are used to extract information on the shape of the PSF for several states but for this paper our focus will be on pairs of $7/2^-$ states as illustrated in Figure 1 below. In the figure statistical error bars were utilized to illustrate the level of uncertainty surrounding the data points. The shape of the PSF is observed to have smaller error bars at high energy primary gamma rays, which is due to higher statistics attained at these energies and enables for more accurate measurements.

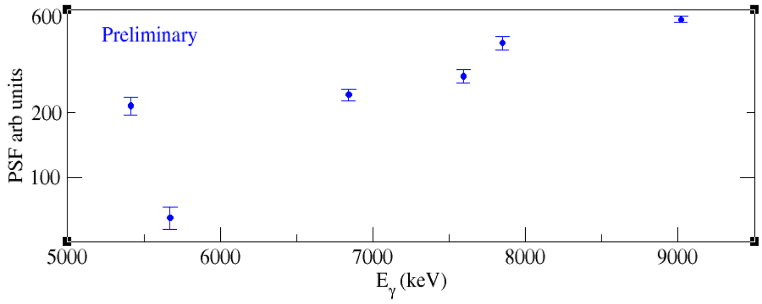

Figure 1. The shape of the PSF in ^{51}Mn extracted from primary gamma rays decaying to final states with J^{π}=7/2^{-}.

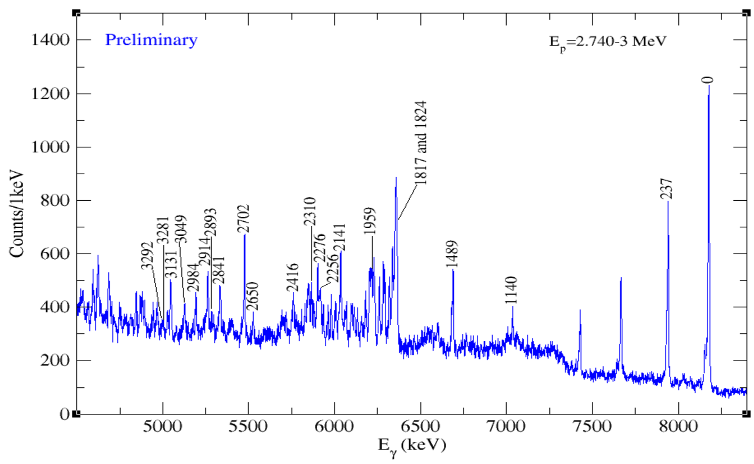

Figure 2. The combined primary gamma ray spectrum of ^{51}Mn obtained by summing 13 primary gamma ray spectra covering the E_P=2.760-3 MeV proton energy range. The peaks are labelled with the energy of the final states.

5. Discussion

The shape of the PSF in ^{51}Mn was measured for a pair of primary gamma ray transitions which were populated at three different excitation energy regions decaying to two 7/2^{-} final states that are at 237 and 2416 keV level excitation energies. The observed slope of the PSF shows an energy dependence of increasing strength with increasing gamma ray energies. Since the comparison was performed on final states of the same J^{π} no models were utilized in determining the slope. This is because the initial level density $\rho(E_i)$, the population cross section $\sigma(E_i, J_i)$ and the spin distribution $g(E_i, J_i)$ of the initial levels that decay to final states of the same spin and parity are also the same. It is often not easy to reliably separate two low-lying discrete states of the same J^{π} but using (p,γ) proton capture reactions together with the ARC method and HPGe detectors make it possible. The success of the ^{50}Cr(p,γ)^{51}Mn proton capture reaction opens doors for this type of a reaction to be used to study neutron-deficient nuclei.

6. Conclusion

The results of this work established that the shape method together with the ARC method may be applied to data from (p,γ) proton capture reactions to obtain the slope of the PSF although more verifying work is ongoing.

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