Investigation of spin-parity conditions for the photonuclear reaction using surrogate ratio method

Shaima Akbar[1],* M.M Musthafa[1], C.V Midhun[1], and S.V Suryanarayana[2]
[1] *Deptartment of Physics, University of Calicut, Kerala - 673635, India and*
[2] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400085, India*

Introduction

Photonuclear reaction data are crucial in various fields, viz., nuclear medicine, nuclear astrophysics, waste transmutation etc. A source of photons is essential for performing photonuclear reactions. Among the different sources, bremsstrahlung photons, generated by an intense electron beam are the most commonly available. However, the cross section can only be obtained after unfolding or averaging the bremsstrahlung spectrum. Alternatively, one can determine the cumulative cross section corresponding to the entire bremsstrahlung spectrum. Due to these challenges with bremsstrahlung beams, methods like the surrogate ratio method(SRM), can be preferable for cross section measurements. SRM technique is developed based on the compound nuclear theory proposed by N.Bohr. In this method, the required compound nucleus is populated through an alternative reaction using an accessible projectile-target combination. A surrogate experiment is depend on the particular decay probability of the compound nucleus populated in a surrogate reaction. Specific spin-parity conditions are to be satisfied to perform a photonuclear reaction via the surrogate ratio method[1]. In this paper, we discuss relavant spin requirements for the selected photonuclear reaction ^{58}Co(γ,xp).

^{58}Co is an important isotope formed in reactors due to the continuous exposure of the reactor's structural material, such as ^{59}Co, to neutron beams. Energetic photons produced within the reactor can induce nuclear reactions with this isotope. In the present study, ^{61}Ni(γ,xp) is used as the reference reaction to determine the surrogate ratio. To perform the SRM, two transfer reactions ^{56}Fe(^{6}Li,α) and ^{59}Co(^{6}Li,α) are used as the surrogate reactions corresponding to the compound nuclei ^{58}Co* and ^{61}Ni* respectively.

Theoretical calculations

The mechanism of photonuclear reactions can be classified based on the incident photon energy. The primary mechanism relevant to photonuclear reactions is the giant dipole resonance, which typically occurs in the energy range of 10-30 MeV. This mechanism is similar to the statistical compound nuclear reaction mechanism, as photon absorption excites the target nucleus to an excited state. In photonuclear absorption, a constant spin distribution across different incident energies is expected due to the electric dipole nature of the process, effective up to 30 MeV. This results in a narrow angular momentum distribution for the compound nucleus, highlighting the usefulness of the surrogate ratio method for photon-induced cross section measurements. However, to ensure the applicability of surrogate ratio method to the photon induced nuclear reactions, we have calculated spin dependent decay probabilities for both desired and reference nuclei using the statistical nuclear reaction code TALYS 1.96[2].

In the present study, protons were the outgoing particles from both compound nuclei. Therefore, the proton decay probabilities for different spin (J) states of the compound nuclei ^{58}Co and ^{61}Ni were calculated in the excitation energy range of 21-32 MeV. These compound nuclei were populated in the surrogate reactions ^{56}Fe(^{6}Li,α) and ^{59}Co(^{6}Li,α). The decay probability for spins up to J= $(9)^{\pm}$

*Electronic address: shaimaakbar333@gmail.com

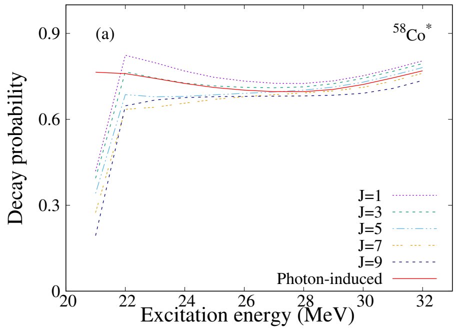

FIG. 1: The decay probabilities for different spin states(J) of ^{58}Co* populated in the surrogate reaction ^{56}Fe(^{6}Li,α) along with same calculated for photon induced reaction ^{58}Co(γ,xp).

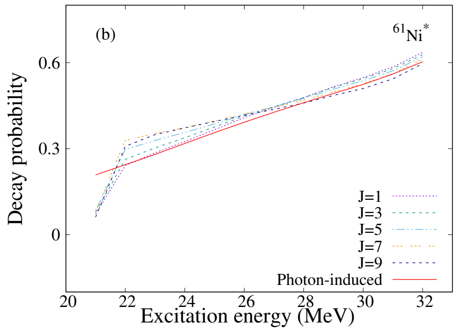

FIG. 2: The decay probabilities for different spin states(J) of the compound nucleus ^{61}Ni populated in ^{59}Co(^{6}Li,α) reaction along with same calculated for photon induced reaction ^{61}Ni(γ,xp).

was calculated, using the populated initial nucleus option available in the TALYS code. To achieve the specific spin-parity states of the compound nuclei within the required energy range, the incident beam option was set to "projectile 0" in the input file of TALYS. This method provided the initial compound nucleus population for specific spin-parity states. The decay probability was then obtained as the ratio of the final residual nucleus population to the initial compound nucleus population. The theoretical calculations relied solely on the compound nucleus model, with the Hartree-Fock-BCS model of level density using Skyrme force applied. Since the calculated decay probabilities exhibited similar behavior across both ($\pm$) parity states, only the variation of decay probability with spin states was presented.

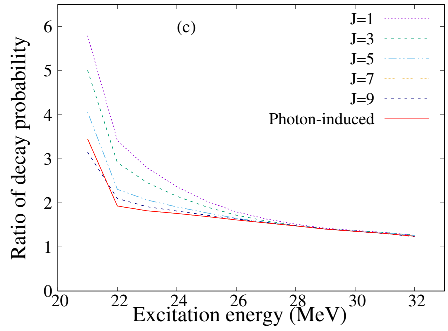

FIG. 3: The ratio of decay probabilities of ^{58}Co to ^{61}Ni for different spin(J) states along with photon induced reaction.

Result and discussion

The decay probabilities for the compound nuclei ^{58}Co and ^{61}Ni, along with those from the ^{58}Co(γ,xp) and ^{61}Ni(γ,xp) reactions, are shown in Figs. 1 and 2, respectively. The figures demonstrate that the decay probabilities of photon-induced nuclear reactions exhibit angular momentum (J) dependency in the energy range considered. However, the ratio of the two decay probabilities(^{58}Co to ^{61}Ni), calculated for each spin state, converges and coincides with the photon-induced reaction curve in the energy range of 27-32 MeV, as shown in Fig. 3. In this range, the theoretical systematic uncertainty is between 8.8% and 4.2%. Below 27 MeV, significant deviations, exceeding 50%, from the photon-induced curve are observed. Therefore, the cross section for the ^{58}Co(γ,xp) reaction can only be accurately determined in the 27-32 MeV energy range, with a theoretical uncertainty of 8.8% to 4.2%.

References

[1] S. Chiba *et. al*, Phy. Rev. C **84**, 054602 (2011)

[2] A. Koning *et. al*, Eur. Phys. J. A **59**, 131 (2023).