Determination of excitation function of ^{61}Ni(γ,xp) reaction using surrogate reaction method

Shaima Akbar[1], Jyoti Pandey[2], M.M. Musthafa[1],*
Midhun C.V.[1], Bhawna Pandey[2], S.V. Suryanarayana[3],
B.K. Nayak[3], H.M Agrawal[2], and S. Santra[3]
[1]*Department of Physics, University of calicut, Malappuram, Kerala, INDIA*
[2]*Department of Physics, G.B Pant University,*
Pantnagar, Uttarakhand 200001, INDIA and
[3]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*

Introduction

The studies on photo-nuclear reactions are important nowadays. The data produced in such reactions have wide applications in radiotherapy, astrophysical nucleosynthesis, radiation shielding design, nuclear waste transmutation and activation analysis[1]. The data are also needed in the reactor in-core dosimetry calculations, estimating the radiation damage of reactor structural materials etc. Most of the photo-nuclear experiments carried out so far are focused on the giant dipole resonance(GDR)[2–4], which is the prominent mechanism for photon energies below 30MeV. Bremsstrahlung photon sources are commonly being used for photonuclear experiments and are easier to produce via betatron or synchrotron. Other facilities such as positron inflight annihilation, laser Compton scattered photons, bremsstrahlung tagged photons are also employed as photon sources[3].

The use of bremsstrahlung photon source requires an unfolding of the obtained spectra in order to obtain the cross section[3]. Even though this method can provide good results for continuous photon source, a number of systematic errors are accumulated in the unfolding technique. One way to overcome this situation is to use high intense mono-energetic photon beams with better resolution. However the production of such photon source is more complicated and presently fewer number of mono-energetic photon facilities are known to exist in the world. An alternative way to measure the photo-nuclear reaction cross section is surrogate reaction method, which is a method that can be used if the cross section of the desired reaction cannot be measured directly[5]. The basic idea of surrogate approach is to populate the same compound nucleus in the desired reaction channel through an alternative feasible direct reaction channel. Surrogate measurements till date are mainly focused on neutron induced fission cross sections. Neutron capture cross sections are also studied over the years. So far no photo-nuclear cross section calculations are performed using surrogate approach. In the present work we are trying to explore the indirect surrogate reaction method to determine the photo-nuclear reaction cross section.

Here we report the measurement of photo-nuclear cross section of ^{61}Ni(γ,xp) reaction, for which experimental data is not available in any of the nuclear data librararies. Nickel isotopes are important as reactor structural material which may be exposed to high energy prompt gamma.

Methods

In order to calculate the cross section of ^{61}Ni(γ,xp) reaction we selected ^{59}Co(^{6}Li,α) transfer reaction as the surrogate pair of ^{61}Ni(γ,xp) reaction and the transfer reaction ^{56}Fe(^{6}Li,d) is considered as the reference reaction which correspond to ^{60}Ni(γ,xp) reaction. Experimental measurements were car-

---

*Electronic address: `mm_musthafa@rediffmail.com` ried out at BARC-TIFR Pelletron Accelerator facility using ^{6}Li beam. The compound nucleus ^{61}Ni* was populated through transfer reaction ^{59}Co(^{6}Li,α) at E$_{lab}$ = 40.5MeV and the compound nucleus ^{60}Ni* was populated through the transfer reaction ^{56}Fe(^{6}Li,d) at E$_{lab}$ = 35.9MeV. The proton decay probabilities of ^{61}Ni* and ^{60}Ni* for the present study are taken from the above experimental data. Present calculations are done by applying the Weisskopf-Ewing approxiamtions of the Hauser-feshbach theory. So the ratio of excitation function of ^{61}Ni* to that of ^{60}Ni* is calculated using the following simplified expression:

$$\frac{\sigma^{61Ni(\gamma,xp)(E^*)}}{\sigma^{60Ni(\gamma,xp)(E^*)}} = \frac{\sigma^{CN}_{\gamma+^{61}Ni}(E^*)\Gamma_p^{61Ni}(E^*)}{\sigma^{CN}_{\gamma+^{60}Ni}(E^*)\Gamma_p^{60Ni}(E^*)} \tag{1}$$

where $\sigma^{CN}(E^*)$ represents photon induced compound nuclear formation cross section and it is calculated using EMPIRE 3.2.2 nuclear reaction code. $\Gamma_p^{CN}(E^*)$ is the proton decay probability of the corresponding compound nucleus. Using Eq. (1) the cross section of ^{61}Ni(γ,xp) reaction is extracted by substituting CN formation cross section, decay probabilities and reference reaction cross section. The cross section of the reference reaction ^{60}Ni(γ,xp) is taken from EXFOR data library[6].

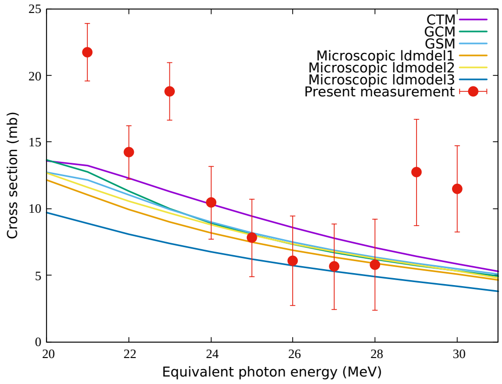

FIG. 1: The ^{61}Ni(γ,xp) cross section as a function of photon energy

Theoretical model calculations

Nuclear model calculations are done using TALYS 1.8 nuclear reaction code for photon energy range 21-30 MeV. The cross section of all the prominent proton emission channels viz ^{61}Ni(γ,p),^{61}Ni(γ,np) and ^{61}Ni(γ,2p) are calculated. Threshold energies for these reactions are 9.8, 17.35, 18.14 MeV respectively. The phenomenological level density models such as Constant temperature model, Backshifted Fermi gas model and Generalised super fluid model are used for theoretical calculations. Parity dependent nuclear level densities based on microscopic combinatorial model with default parameter values are also employed.

Result and Discussion

The excitation function of ^{61}Ni(γ,xp) reaction is obtained using surrogate reaction method The results are shown in fig. 1. From the figure it is clear that the results are in agreement with the theoretical calculations at an intermediate energies(24-28 MeV). There are deviations in lower and higher energy region, the source of these deviations are to be studied. In order to reach a better conclusion more experimental data have to be verified using this method.

Acknowledgments

This work is a part of DAE-BRNS supported research project, Sanction Order :36(6)/14/30/2017-BRNS/36204.

References

[1] Handbook on photo-nuclear data for application IAEA-TECDOC-Draft No 3.
[2] W.A Lochstet and W.E Stephens Phys.Rev C Vol. 141, N0.3, (1966)
[3] B.L Berman et al Rev. Mod. Phys. Vol. 47, No. 3, (1975).
[4] R. Carchon et al Phys.Rev C Vol. 14, N0.2, (1976)
[5] J.E Escher et al Rev. Mod. Phys. Vol. 84, No. 1, (2012)
[6] B.S Ishkhanov et.al J,SNP,11,272,(1970)