Development of ^{7}Li(p,n)^{7}Be Neutron Energy Spectrum Code and Measurement of Neutron Radiative Capture Cross-Section on Few Structural Elements in the keV Neutron Energy Region

Rebecca Lalnuntluangi*
Department of Physics, Mizoram University,
Tanhril-796004, Aizawl, Mizoram, INDIA

Introduction

The neutron-induced reactions on Zinc isotopes have many applications in nuclear science and engineering. We have measured the ^{70}Zn(n,γ)^{71m}Zn ($T_{1/2}$=3.96 hrs) activation cross sections using the ^{7}Li(p,n)^{7}Be neutron source at E_p=2.25 MeV and 2.60 MeV at BARC-FOTIA. Since the time-of-flight and multiple foil activation techniques cannot be applied at BARC-FOTIA due to the continuous beam structure and weak neutron flux, we have to rely on calculated neutron energy spectra for subtraction of the ^{7}Li(p,n_1)^{7}Be contribution to ^{71m}Zn production. There are some codes such as PINO [1] and SimLiT [2] for calculation of ^{7}Li(p,n)^{7}Be neutron source spectra but there are serious discrepancies between the neutron spectra predicted by the two codes and it was impossible to understand the correct one. We, therefore, decided to study the thick and thin target ^{7}Li(p,$n_{0,1}$)^{7}Be neutron spectra by developing a new deterministic code **EPEN** (**E**nergy of **P**roton **E**nergy of **N**eutron).

To examine the approach near the threshold region, the shape of the ground state angular-integrated neutron energy spectrum at E_p=1912 keV were validated by experimental data. The comparison result is shown in Fig.1.

At higher incident energies (E_p=2800), the angular-integrated ground state and first excited state neutron energy spectra predicted by EPEN were also compared with those predicted by SimLiT and PINO, and observed that EPEN and SimLiT shows almost perfect agreement for both (p,n_0) and (p,n_1) neutron energy spectra for thin and thick lithium target with and without proton energy spread while PINO shows completely different result. The comparison result is shown in Fig.2. For all users around the globe, EPEN is now freely available at Mizoram University website (http://www.epen.nhergmzu.com/epen/).

Details of Experiment

The experiment was carried out at the Folded Tandem Ion Accelerator (FOTIA) Facility, Nuclear Physics Division, Bhabha Atomic Research Centre (BARC), Mumbai. The neutron beam was obtained from the ^{7}Li(p,n)^{7}Be reaction. The energies of proton beam were 2.25 MeV and 2.60 MeV with energy spread of ±0.02 MeV. The thickness of the lithium targets used for irradiation at 2.25 and 2.60 MeV proton energies were 2.0 mg/cm2 (37.4 μm) and 2.5 mg/cm2 (46.8 μm) respectively. The proton beam current during irradiation varied from 50 to 100 nA, and the beam diameter on the lithium target was about 5 mm. A 0.25-mm-thick tantalum foil (manufactured by Goodfellow Cambridge Limited, United Kingdom and supplied by H. Fillunger & Co. Pvt. Ltd., Bangalore) on which the lithium target was pasted was used as a proton beam stopper. The time structure of the neutron flux was monitored online by a NE213 neutron detector at 0 and at 1-m distance from the lithium target. The neutron flux was recorded and saved every 30 min to get the neutron flux fluctuation during the whole irradiation period.

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*Electronic address: `pcrl.bec@gmail.com`

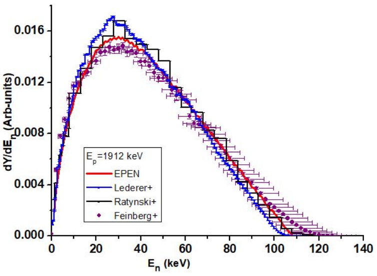

FIG. 1: Comparison of EPEN ^{7}Li(p,n$_0$)^{7}Be neutron energy spectrum at E$_p$=1912 ± 0 keV with experimental results for a thick natural lithium target.

TABLE I: The ^{70}Zn(n,γ)^{71m}Zn cross sections measured in the present and previous experiments with their total uncertainties and correlation coefficients.

E$_n$ MeV	$<\sigma_{Zn^m}>$ (mb)	Corr. coeff.			
0.40	1.82±0.11	1.00			
0.70	1.99±0.06	0.38	1.00		
0.96	1.83±0.16	0.13	0.27	1.00	
1.69	1.33±0.10	0.17	0.33	0.12	1.00

Results and discussions

The ^{70}Zn(n,γ)^{71m}Zn reaction cross sections newly determined in the present work at neutron energies 0.40 MeV and 0.70 are given in Table I along with our earlier measured cross sections at 0.96 MeV and 1.69 MeV [3] . The measured spectrum averaged ^{70}Zn(n,γ)^{71m}Zn reaction cross sections at the four energies and the cross sections for monoenergetic neutrons calculated by nuclear reaction model code TALYS-1.8 are also compared. The comparison result shows that the TALYS-1.8 with the generalized superfluid level density model (LDM-3) best matches the measured cross sections except for 1.69 MeV where the measured cross section is slightly overestimated by TALYS-1.8. The result is shown in Fig.3.

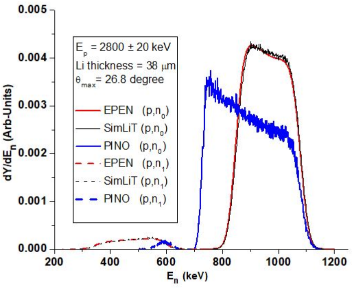

FIG. 2: Comparison between EPEN, SimLiT and PINO neutron energy spectra for thin lithium target thickness 38 μm at Ep = 2800±20 keV

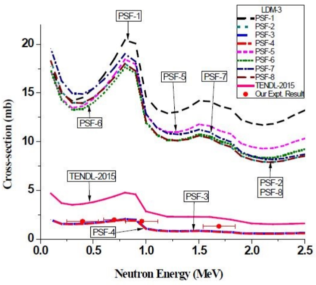

FIG. 3: Excitation functions of the ^{70}Zn(n,γ)^{71m}Zn cross sections measured by us, evaluated in TENDL-2015 (solid line) as well as predicted by TALYS-1.8.

Conclusion

The ^{70}Zn(n,γ)^{71m}Zn reaction cross sections have been measured just below and above the inelastic scattering threshold energy using standard activation technique. The comparison showed that TALYS-1.8 with the generalized superfluid level model (LDM-3) and Hartree-Fock BCS (PSF-3) or Hartree-Fock-Bogolyubov (PSF-4) γ-ray strength functions best matches the measured cross sections.

References

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[2] M. Friedman et al., Nucl. Instr. Meth. Phys. Res. A, **698**, 117 (2013).
[3] L.R.M. Punte et al., Phys. Rev. C **95**, 024619 (2017).