Production of ^{68}Ga from the ^{7}Li-induced reaction on Cu

Rishabh Kumar[1], Rinku Prajapat[1], Gayatri Sarkar[1], Amit Chauhan[1], Moumita Maiti[1,*] T. Nag[2], and S. Sodaye[2]
[1] *Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, INDIA and*
[2] *Radiochemistry Division, Bhabha Atomic Research Centre, Mumbai-400085, INDIA*

Introduction

Physics of nuclear reaction has evolved extensively from its first appearance. There has been quite a stir to study low energy fusion reaction of heavy-ions on intermediate or heavy mass targets due to the unanticipated observation of new phenomena like pre-equilibrium (PEQ) emissions, complete and incomplete fusion reactions, nucleon transfer processes, etc. Study of nuclear reactions with weakly bound stable (^{6,7}Li, ^{9}Be) and unstable (^{6}He, ^{11}Li, ^{11}Be) projectiles have generated significant interest to explore those processes in depth [1]. PEQ emission is observed at the high energy tail of the excitation function, and it starts competing with the compound mechanism due to the availability of high energy and angular momentum at the excited composite system. Measurement of excitation function of the residues over a wide energy range helps to understand the fundamental reaction mechanisms such as equilibrium (EQ) and PEQ processes, and also to check the applicability of different nuclear reaction models, etc. Although PEQ emission studies for weakly bound projectiles have been reported for some cases [2], yet more experimental data are required in the intermediate and low mass region to study PEQ processes over EQ comprehensively.

Further, ^{68}Ga (67.71 min) is one of the noble radionuclides which has found applications in the medical field as a positron emitter. Nuclear spectroscopic data of ^{68}Ga has been tabulated in Table I. There have been constant efforts to produce ^{68}Ge (270.93 d), which decays to ^{68}Ga, so that ^{68}Ge could be used as a generator for ^{68}Ga. Apart from this, a number of methods to produce ^{68}Ga have been reported, cyclotron production of ^{68}Ga via ^{68}Zn(p,n)^{68}Ga [3] and ^{nat}Cu(α,xn)^{66,67,68}Ga reactions [4] among them.

In this article, we report the cross-section measurement of ^{68}Ga from the ^{7}Li induced reaction on ^{nat}Cu up to 44 MeV.

Experiment

The experiment was carried out at the BARC-TIFR Pelletron Facility, Mumbai, India. The ^{7}Li beam was bombarded on the stacks of ^{nat}Cu foils having thickness $\sim$ 1.7-2.5 mg/cm^2, and each foil was supported by the aluminum catcher foils of thickness $\sim$ 2.3 mg/cm^2 within 21.5-43.5 MeV range of energy. After the end of the bombardment, the activity of the residual radionuclides produced in the Cu target at various incident energies was measured with the help of γ-spectrometry and the cross-sections have been calculated from the background-subtracted peak area count rate. The error associated with the cross-sections is estimated considering all possible sources, and the data are presented up to 95% confidence level.

TABLE I: Spectroscopic data of ^{68}Ga and production channels

Nuclide ($T_{1/2}$)	Decay mode (%) [$E_{\beta+}$keV($I_{\beta+}$%)]	E_γ(keV) (I_γ%)	Production Channel	E_{th} (MeV)
^{68}Ga (67.71 min)	EC+β^+ (100) [352.59 (1.19), 836.02 (87.72)]	1077.35[3.22]	^{63}Cu(^{7}Li,pn)^{68}Ga	0.0
			^{65}Cu(^{7}Li,$p3n$)^{68}Ga	18.6
			^{63}Cu(^{7}Li,$2n$)^{68}Ge	0.0
			^{65}Cu(^{7}Li,$4n$)^{68}Ge	19.6
			^{68}Ge $\xrightarrow{EC}$ ^{68}Ge	

Results and discussion

A total of eight radionuclides have been identified by the γ-rays spectrometry in this experiment. These radionuclides are: (1) ^{69}Ge (39.05 h), ^{67}Ge (18.9 min), ^{66}Ge (2.26 d) produced via xn channel, (2) ^{68}Ga (67.71 min),

*Electronic address: moumifph@iitr.ac.in

^{67}Ga (3.2617 d), ^{66}Ga (9.49 h) produced via *pxn* channel, and ^{65}Zn (243.93 d), ^{63}Zn (38.47 min) produced via αxn channel. However, the focus of this abstract would be on ^{68}Ga.

Fig.1 shows a comparison between the measured cross-sections of ^{68}Ga radionuclide and the theoretical model calculations obtained from PACE4 and EMPIRE-3.2. Both the codes are based on the Hauser-Feshbach (HF) formalism of compound nuclear decay; however, PACE4 considers EQ emission only, while EMPIRE-3.2 takes into account of EQ and PEQ emissions. PACE considers the angular momentum projection at each stage of de-excitation, which allows measurement of the angular distribution of emitted particles. Complete fusion cross-section in PACE4 is estimated using the Bass barrier potential. The Gilbert-Cameron level density has been used with level density parameter a=A/10, where A is the mass number of the compound nucleus, in the PACE4 estimation. EMPIRE employs the Exciton model to account for the PEQ emissions. We have used the Generalized Superfluid Model to calculate the nuclear level density in EMPIRE.

It is observed that at low energy, PACE-4 almost predicts the experimental cross-section while EMPIRE underpredicts them. At energies above 28 MeV, PACE4 underpredicts experimental cross-sections by quite a margin, while EMPIRE better reproduces the trend of cross-section data in this region yet with slight underprediction. Production of ^{68}Ga is expected mostly from the *pxn* channels: ^{65}Cu(^{7}Li,*p*3*n*) and ^{63}Cu(^{7}Li,*pn*)^{68}Ga, however, it could also be produced from the decay of ^{68}Ge, which would be produced spontaneously from the *xn* channel. Therefore, measured cross-section of ^{68}Ga is expected to be cumulative from both the routes (see Table I). It is worthy to mention here that ^{68}Ge is not measured in this experiment because of no suitable characteristic γ-ray. It is also evident from Fig.1 that EMPIRE estimated cumulative cross-sections (^{68}Ge+^{68}Ga) well reproduce the measured cross-sections of ^{68}Ga throughout the energy range. The observed difference between the PACE4 and EMPIRE estimations, particularly beyond 30 MeV, is essentially due to the consideration of PEQ model in the later, hence this study also confirms the presence of PEQ effect in the higher energy region of the excitation function.

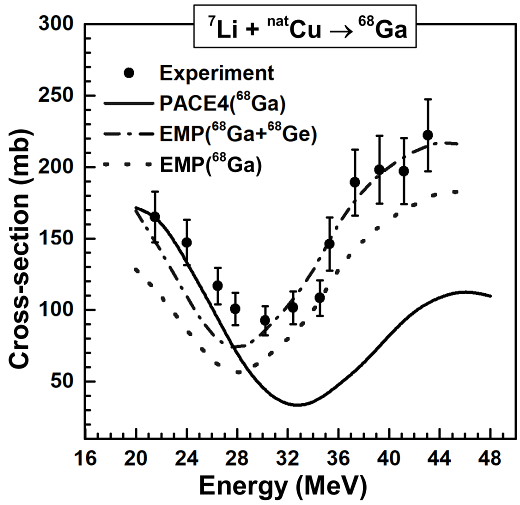

FIG. 1: Comparison of the measured cross-sections of ^{68}Ga and theoretical excitation functions.

Conclusion

The production cross-section for ^{68}Ga from the ^{7}Li+^{nat}Cu reaction within ∼ 3.1-6.2 MeV/A has been reported. The HF+Exciton model used for EQ and PEQ emissions grossly reproduces the experimental cross-section as compared to only HF model.

Acknowledgment

Research grant from SERB CRG/2018/002354, and the fellowships from INSPIRE, DST and MHRD, Government of India, are gratefully acknowledged.

References

[1] L. F. Canto *et al.,* Phys. Rep. **596**, 1 (2015).
[2] D. Kumar *et al.,* Phys. Rev. C **94**, 044603 (2016).
[3] M. K. Pandey *et al.,* Am. J. Nucl. Med. Mol. Imaging. **4**, 303 (2014).
[4] F. Szelecsenyi *et al.,* Radiochim. Acta. **100**, 5 (2012).