Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Photonuclear Reaction Cross Sections for Gallium Isotopes

To cite this article: S Akkoyun *et al* 2015 *J. Phys.: Conf. Ser.* **590** 012047

View the article online for updates and enhancements.

Related content

- Photonuclear reactions induced by a clinical linac
I Boztosun, H Dapo, M Karakoc et al.
- Experiments with brilliant gamma beams at ELI-NP: A glimpse in the future
Dimiter L. Balabanski
- Transmutation of nuclear wastes using photonuclear reactions triggered by Compton backscattering photons at the Shanghai laser electron gamma source
Chen Jin-Gen, Xu Wang, Wang Hong-Wei et al.

Recent citations

- Energy level and half-life determinations from photonuclear reaction on Ga target
Serkan Akkoyun *et al*



IOP ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection–download the first chapter of every title for free.

This content was downloaded from IP address 193.140.168.237 on 09/06/2020 at 11:21

Journal of Physics: Conference Series **590** (2015) 012047 doi:10.1088/1742-6596/590/1/012047

Photonuclear Reaction Cross Sections for Gallium Isotopes

S Akkoyun[1,*], T Bayram[2], SO Kara[3]
[1]Vocational School of Health Services, Cumhuriyet University, Sivas, Turkey
[2]Department of Physics, Sinop University, Sinop, Turkey
[3]Bor Vocational School, Nigde University, Nigde, Turkey

E-mail: serkan.akkoyun@gmail.com

Abstract. The photon induced reactions which are named as photonuclear reactions have a great importance in many field of nuclear, radiation physics and related fields. The cross-sections of neutron (photo-neutron (γ,xn)) and proton (photo-proton (γ,xn)) productions after photon activation have been calculated by using TALYS 1.2 computer code in this study. The target nucleus has been considered gallium which has two stable isotopes, ^{69}Ga and ^{71}Ga. Furthermore, the pre-equilibrium and compound process contributions to the total cross-section have been investigated.

Introduction

Photonuclear reactions have been used in basic and applied sciences in nuclear and radiation physics related fields [1-4]. When a gamma-ray is incident upon a nucleus, the excited nucleus behaves like any compound nucleus with an excitation energy. The most probable decay is neutron emission (γ,n). After this, (γ,2n), (γ,1p) and (γ,2p) reactions take part. Nuclear level and half-life identifications, nucleon binding energy determinations, material analysis, radiation protection applications, dosimetry, absorbed dose assessment, activation analysis, radiation transport analyses, physics of fission and fusion reactors, nuclear waste transmutations and understanding element creations by astrophysical processes can be given as examples to such studies [2,4]. The experimental studies on these reactions have begun in 1934 [5] but there are still lack of existing data. Therefore, systematic studies of these reactions on different nuclei have been needed. The advantages of the reaction by photon activation are determination of the multiple element simultaneously, non-destructive structure of the process, requiring no time-consuming chemical separation procedure, deeper penetrating capability of the photon into the target [6]. The excited nucleus in the target emits particular radiation or photons in order to get rid of its excess energy. Due to the fact that photon do purely electromagnetic interaction with nuclei, the process is non-destructive.

Two main types can be observed when two nuclear system collide and both are very important in order to understand nuclear reaction phenomena. In the compound nucleus reaction, two system collide and a highly excited intermediate system has been created. The compound system has been formed by a sequence of collisions leading to rearrangements of the target nucleus. The excitation energy has been shared by nucleons. After sharing by chance, the overall energy has been localized on one or more or a group of nucleons for it to escape from the compound system. If there is still sufficient energy, further particle emission may occur, otherwise beta or gamma decay will appear. Second type which takes place very quickly according to the compound nucleus reactions has been

[1] To whom any correspondence should be addressed.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

named as direct reaction. In this type, there is no intermediate compound system formed. In the compound nucleus formation, the projectile passes into the interior of the nucleus suffering a number of collisions. Therefore, we have expected that the direct reactions are localized in the nuclear surface (projectile interact over the surface of the nucleus) whereas compound nuclear reactions are localized in the interior of the nucleus. For increasing energy or nuclei for which the compound nucleus does not have time to reach thermodynamic equilibrium, pre-equilibrium or direct processes may become significant.

The cross section of the pure compound process is very small with respect to the measured spectra. Additionally, the measured angular distributions are not isotropic as expected isotropic in compound nucleus decays. So, there will be another classification between direct and compound nucleus mechanism. The pre-equilibrium process falls into either category. In these reactions, a nucleon is emitted after a number of collisions have occurred. Pre-equilibrium process [7] contributes to reaction cross-section in the 10 and 200 MeV energy range. In order to describe the pre-equilibrium mechanism, the exciton model is widely used [8]. At any time during the reaction, the nuclear state is characterized by the total energy, the total number of particles above the Fermi surface and total number of holes below the Fermi surface. Particles and holes are referred to as excitons. The complete formalism of the exciton model has been included in the TALYS reaction code [9]. By using the TALYS, it is possible to obtain all the compound nucleus, pre-equilibrium, and direct reactions contributions to the nuclear reactions.

Gallium element has two stable isotopes and both are used in nuclear physics and nuclear medicine. ^{69}Ga isotope has been used for ^{68}Ge or ^{68}Ga generators. The ^{68}Ga which is a positron emitter has been used as a PET isotope. ^{71}Ga has been used in the study of behavior of solar neutrinos and in NMR studies. In this work, the photo-neutron and photo-proton cross sections as a function of photon energy with one and two nucleon in out channels have been investigated by using the TALYS 1.2 computer program. The reactions considered were (γ,1n), (γ,2n), (γ,1p) and (γ,2p). There is very limited photonuclear reaction cross section data in the literature for gallium [10, 11].

In this work, the photo-neutron and photo-proton cross sections of gallium isotopes have been calculated according to the photon energy in the 0.5-30 MeV energy range by using TALYS 1.2 computer program. Default options have been used in the program. The compound nucleus and pre-equilibrium mechanism contributions have been also analyzed for gallium isotopes as done in a systematic study in reference [13]. The results have been compared with the TENDL-2013 [12] databases.

2. Results and Discussion

In this work TALYS 1.2 version of the code has been used for the calculations of the (γ,1n), (γ,2n), (γ,1p) and (γ,2p) reaction cross-sections performed on both ^{69}Ga and ^{71}Ga targets separately. Pre-equilibrium and compound reactions cross sections have contributed to the overall cross sections. The energies of the gamma-rays have been between 0.5 and 30 MeV with 0.5 MeV interval. The reaction Q values are -10.3 and -6.6 MeV for ^{69}Ga(γ,1n)^{68}Ga and ^{69}Ga(γ,1p) ^{68}Zn reactions, respectively. Besides for ^{71}Ga isotopes these value are -9.3 and -7.9 MeV for ^{71}Ga(γ,1n)^{70}Ga and ^{71}Ga(γ,1p)^{70}Zn reactions, respectively. Furthermore for two nucleon separations the Q values are -18.6, -16.6, -16.9 and -19.0 MeV for ^{69}Ga(γ,2n)^{67}Ga, ^{69}Ga(γ,2p) ^{67}Zn, ^{71}Ga(γ,2n)^{69}Ga and ^{71}Ga(γ,2p)^{69}Zn reactions, respectively. These are the threshold energies for taking place the reactions. As can be seen in the figures that the cross sections are zero below these threshold values.

It is also clear in the Figure 1 that the cross sections for photo-proton reactions has been lower than that of the photo-neutrons because of the suppression by the Coulomb barrier. For instance, for 14 MeV incident photon energy on ^{69}Ga target, the (γ,1n) reaction cross section is about 60 mb whilst the (γ,1p) reaction cross section is only about 3.3 mb for the same energy value. It is clear in Figure 1 that the photo-neutron cross section is almost 2 to 20 times larger than photo-proton cross section in the energy range 10.5 and 30 MeV. Since the threshold energy for the photo-proton reaction is lower than the photo-neutron reaction, there is a probability that occurring photo-proton reaction in the range of

7.5 and 10 MeV where photo-neutron cross is zero. As can be seen in the Figure 1 that after 19 MeV, (γ,2n) reaction become taking place. Until 20.5 MeV the (γ,1n) reaction cross section is larger than that of (γ,2n) reaction. But after this energy value, (γ,2n) become about 1.2 to 5.5 magnitude larger up to 30 MeV. Furthermore (γ,1p) reaction cross section is larger about $6x10^{1}$ to $9x10^{5}$ than (γ,2p) cross section. Finally, the (γ,2n) cross section is too larger than that of (γ,2p) cross section about $1x10^{3}$ to $1x10^{7}$ magnitude.

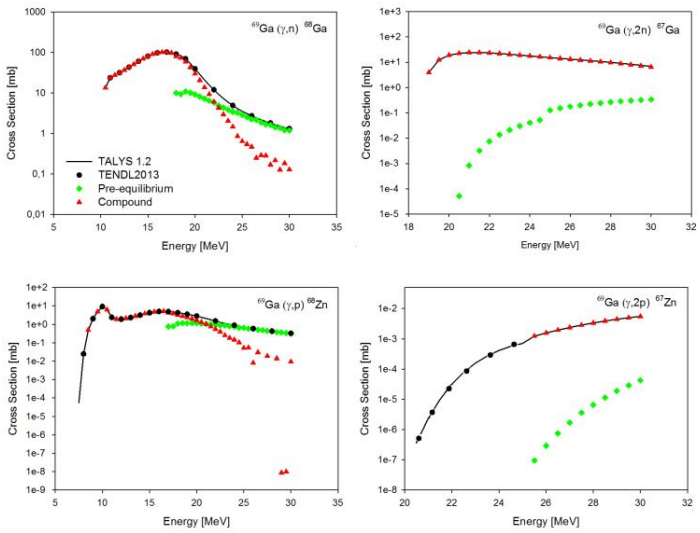


Figure 1 (γ,1n), (γ,1p), (γ,2n) and (γ,2p) cross sections for ^{69}Ga nuclei. Comparisons of pre-equilibrium and compound mechanism.

As can be seen in the Figure 1 that the (γ,1p) reaction cross section sharply increases from threshold energy to about 10.5 MeV where (γ,1n) channel opens up. At this value the increase remains slowly and after about 17 MeV, it becomes decrease because of increasing of the new opening channels such as (γ,2p) and (γ,2n). Besides, the (γ,1n) cross section exhibits similar trend. It increases to 17 MeV and decreases from this point where (γ,2p) and other reaction channels open up. The compound mechanism is dominant to about 20 MeV for (γ,n) ans (γ,p) reactions on the ^{69}Ga target. After this energy value, pre-equilibrium mechanism become dominant to the end. For (γ,2n) and (γ,2p) reactions, the compound mechanism is always dominant.

Similar behavior has been seen for ^{71}Ga target, but the differences is larger. The (γ,1n) reaction cross section is about 50 mb whilst the (γ,1p) reaction cross section is only about 0.3 mb for the 14 MeV energy value. It is clear in Figure 2 that the photo-neutron cross section is almost 4 to $9x10^{2}$ times larger than photo-proton cross section in the energy range 9.5 and 30 MeV. Since there is no explicit difference between neutron and proton thresholds, the reaction probabilities take values in the same energy, 9.5 MeV. As can be seen in the Figure 2 that after 17 MeV, (γ,2n) reaction become taking place. Until 19 MeV the (γ,1n) reaction cross section is larger than that of (γ,2n) reaction. But after this energy value, (γ,2n) become about 1.2 to 7.8 magnitude larger up to 30 MeV. Furthermore (γ,1p) reaction cross section is larger about $2x10^{3}$ to $5x10^{5}$ than (γ,2p) cross section. Finally, the (γ,2n) cross section is too larger than that of (γ,2p) cross section about $7x10^{4}$ to $2x10^{7}$ magnitude. The compound mechanism is dominant to about 20 MeV for (γ,n) ans (γ,p) reactions on the ^{69}Ga target. After this energy value, pre-equilibrium mechanism become dominant to the end. For (γ,2n) reaction, the compound mechanism is always dominant.

Generally, the cross sections for ^{69}Ga target is larger than that of the cross sections of ^{71}Ga for (γ,1n), (γ,1p) and (γ,2p) reactions. This difference is slight for (γ,1n) reaction. But for (γ,2n) reaction, the cross section of the reaction performed on ^{71}Ga target is larger. The cause of this behaviour can be

interpreted through reaction threshold energies. Because the (γ,2n) reaction threshold energy for ^{71}Ga is larger than that of the ^{69}Ga, the probability to happen ^{71}Ga(γ,2n)^{69}Ga reaction is higher. The threshold energies are closer to each other for (γ,1n) reactions, because there is a slight difference between the cross sections of the different targets.

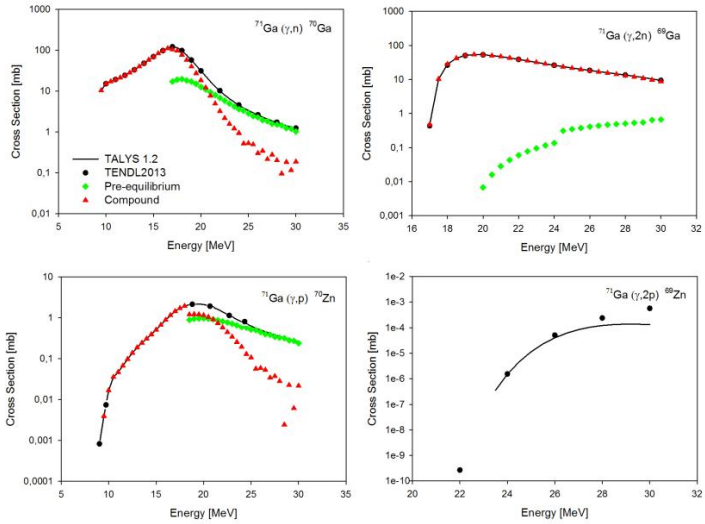


Figure 2 (γ,1n), (γ,1p), (γ,2n) and (γ,2p) cross sections for ^{71}Ga nuclei. Comparisons of pre-equilibrium and compound mechanism.

3. Conclusions

The stable gallium isotopes have been considered as a target nuclei in photonuclear reaction simulations. According to the results, we have seen that the calculations are in harmony with the TENDL-2013 database. The most probable decay channel is photo-neutron reaction whose cross section is 2 to 20 times larger than that of the photo-proton reaction. By increasing the photon energy, (γ,2n) reaction becomes dominant according to the (γ,n) after about 20 MeV. The pre-equilibrium process is dominant in the high energy region, 20-30 MeV. Besides the compound process contribution to the total cross-section is larger than the others in the 10-20 MeV energy interval.

References

[1] Schumacher M 1988 *Inst. Phys. Conf. Ser.* No. **88**/*J. Phys. G:Nucl. Phys.* **14** Suppl., S235-S255
[2] Segebade C and Berger A 2008 *Encyclopedia of Analytical Chemistry* R.A. Meyers, John Wiley & Sons Ltd.
[3] Strauch K 1953 *Annu. Rev. Nucl. Sci.* **2**, 105-128
[4] IAEA-TECDOS-1178 2000 *Handbook on photonuclear data for applications Cross-sections and spectra* IAEA in Austria
[5] Chadwick J and Goldhaber M 1934 *Nature* **134** 237-238
[6] Green J Zaijing S Wells D and Maschner H 2011 *AIP Conf. Proc.* **1336** 497-501
[7] Hodgson PE 1981 *Nature* **292** 671-672
[8] Griffin JJ 1966 *Phys. Rev. Lett.* **17** 478-481 (Erratum: *Phys. Rev. Lett.* **19** 57).
[9] http://www.talys.eu/
[10] EXFOR, https://www-nds.iaea.org/exfor/servlet/X4sSearch5
[11] Carlos P Beil H Bergere R Fagot J Lepretre A Veyssiere A Solodukhov GV 1976 *Nucl. Phys. A* **258** 365-387
[12] TENDL-2013, http:// http://www.talys.eu/tendl-2013/
[13] Xu Y Goriely S Koning AJ and Hilaire S 2014 *Phys. Rev. C* **90** 024604