Energy Levels and Half-Lives of Gallium Isotopes Obtained by Photo-Nuclear Reaction

F Dulger\textsuperscript{1,2}, S Akkoyun\textsuperscript{3}, T Bayram\textsuperscript{4}, H \Upsilon apo\textsuperscript{1,2} and I Boztosun\textsuperscript{1,2}

\textsuperscript{1} Akdeniz University, Department of Physics, 07058, Antalya, Turkey
\textsuperscript{2} Akdeniz University, Nuclear Sciences Application and Research Center, 07058, Antalya, Turkey
\textsuperscript{3} Cumhuriyet University, Vocational School of Health, Sivas, 58140, Turkey
\textsuperscript{4} Sinop University, Department of Physics, 57000, Sinop, Turkey

E-mail: fatihdulger@akdeniz.edu.tr

Abstract. We have run an experiment to determine the energy levels and half-lives of Gallium nucleus by using the photonuclear reactions with end-point energy of 18 MeV bremsstrahlung photons, produced by a clinical linear accelerator. As a result of $^{71}\text{Ga}(\gamma,n)^{70}\text{Ga}$ and $^{69}\text{Ga}(\gamma,n)^{68}\text{Ga}$ photonuclear reactions, the energy levels and half-lives of $^{70}\text{Ga}$ and $^{68}\text{Ga}$ nuclei have been determined. The results are in good agreement with the literature values.

1. Introduction
High-energy electrons can be used to produce bremsstrahlung photons by a linear accelerator. These photons are obtained by the bombardment of a tungsten (W) or tantalum (Ta) bremsstrahlung converter with electrons. The sample is placed downstream behind the converter and thus is exposed to bremsstrahlung photons. Due to activation, the stable nuclei in the sample can be transformed to radioactive ones. A neutron and proton separation is induced by the interaction of bremsstrahlung photons produced by the linear accelerator, viz. photo-nuclear reactions. This is called photo-activation technique [1]. Based on this technique, the photonuclear experiments are conducted in two steps: the irradiation and the residual activity measurement. Although there are available different techniques of measurement for the photo-nuclear reaction products, this is the most widely used one.

During a photonuclear reaction, energy of a high energy gamma-ray photon is absorbed fully or partially by the nucleus forcing it into an excited state. From this excited state, the nucleus can emit any particle (p, n, etc), provided it has enough energy for such a process to occur. Subsequently, the radiation emitted from the radioactive nuclei is determined by counting it with an appropriate spectrometer. In this way, we can obtain information about the energy levels and half-lives of the created isotopes. This method has a wide range of applications in the medical imaging systems, radioisotope treatment process and radiation protection measures.

So far, many experiments have been performed to determine the energy transitions of stable nuclei. In this area, the most comprehensive study to determine the half-life and the energy levels was measured by Oka \textit{et al.} [2]. They have determined the half-lives of 75 different nuclei and observed ($\gamma,n$), ($\gamma,2n$), ($\gamma,p$), ($\gamma,\gamma'$) reactions. In addition, the half-life of $^{68}\text{Ga}$ was investigated by Oka \textit{et al.} [2]. In this study, as a result of $^{69}\text{Ga}(\gamma,n)^{68}\text{Ga}$, the half-life of $^{68}\text{Ga}$ was found to be 68 minute by using scintillator detectors. After the 1970s, this procedure was used for many scientific purposes.
country, for the first time in 2013, this was done by Akdeniz University Nuclear Sciences Application and Research Center (NUBA) by using the local facilities. In this study, Boztosun et al. [3] studied the half-lives and the energy levels of zinc nuclei.

The target nucleus gallium we study in this paper has two stable isotopes $^{69}$Ga and $^{71}$Ga. Their natural abundances are 60.10% and 39.90% for $^{69}$Ga and $^{71}$Ga, respectively. In this paper, our aim is to determine the energy transitions and half-lives of gallium isotopes by using photonuclear reactions. We have used a high-purity germanium detector to obtain more accurate results. Notably, comparing scintillation and HPGe detectors the latter has better resolution while the former has better efficiency. For the measurement of the energy transition, accuracy is the main goal, therefore we have used a HPGe detector for the counting of residuals [4].

In the next section, we describe the experimental methods. Thereafter, we present the results, followed by our conclusions and outlook.

2. Experimental

The activation technique based on the detection of residual radioactivity of unstable nuclei produced by the reactions during the irradiation phase. By measuring the activity with a high resolution spectrometer, one obtains characteristic gamma ray spectra of decay in unstable reaction products. Thus, specific reactions can be identified.

In this study, the sample prepared for the experiment was placed 58 cm away from the tungsten converter. Photo-nuclear reactions are obtained by exposing the targets with sufficient energy bremsstrahlung photons. Typically, the irradiation time was 1 or 2 hours; subsequently, counting was performed. Counting time at the HPGe detector after irradiation was optimized depending on the half-life of the radioisotope. After data acquisition, spectra were exported to the gf3 Radware gamma spectroscopy software [5].

Figure 1 shows a schematic of the electronics used in the detection and transmission of the signal from the detector to the computer.

![Figure 1. Operating sketch of the HPGe detector](image-url)
3. Results

Figure 2 shows the count versus channel spectrum of the irradiated target nuclei measured by HPGe spectrometry [4]. The spectrum analysis is carried out using the gf3 Radware gamma spectroscopy software [5]. After the peak positions are determined, the energy of transition is obtained by energy calibration using several standard sources (\(^{60}\)Co, \(^{54}\)Mn, \(^{57}\)Co, \(^{24}\)Na, \(^{137}\)Cs, and \(^{133}\)Ba). In addition, the time evolution of the counts yields the respective half-lives. Table 1 shows some of resulting half-lives obtained. The left side of Table 1 shows the literature data, in the right side our results for energies and half-lives are presented. We note that all our uncertainty are only statistical.

![Galium spectrum](image)

**Figure 2.** Spectrum of gallium nuclei

The results obtained for energy transitions show overall good agreement with the literature data. For a true estimate of the quality of the data, we need to also find a way to handle the systematic deviations. Currently, we are reviewing such procedures. While the uncertainty estimation will certainly change, the peak positions will remain. For the half-lives, the situation is not nearly as good. One can observe about 10% discrepancy across all results. The probable causes of this discrepancy are the presence of more than one isotope in our sample. For the time being, it would be difficult for us to circumvent this, but we are working on it.
# Table 1. Results of Our Analysis for $^{71}$Ga and $^{69}$Ga

| Nucleus | Energy (keV) | err  | T$_{1/2}$ (minute) | err  | Energy (keV) | Stat. err | T$_{1/2}$ (minute) | Stat. err |
|---------|--------------|------|-------------------|------|--------------|-----------|-------------------|-----------|
| $^{71}$Ga($\gamma$,n)$^{70}$Ga | 176.17 | 0.02 | 21.14 | 0.03 | 175.74 | 0.02 | 20.10 | 0.05 |
|         | 1039.20 | 0.03 | 21.14 | 0.03 | 1039.44 | 0.01 | 20.28 | 0.02 |
| $^{69}$Ga($\gamma$,n)$^{68}$Ga | 805.83 | 0.08 | 67.71 | 0.09 | 805.91 | 0.2 | 65.06 | 0.36 |
|         | 1077.34 | 0.05 | 67.71 | 0.09 | 1077.404 | 0.004 | 66.12 | 0.04 |
|         | 1230.93 | 0.13 | 67.71 | 0.09 | 1230.92 | 0.08 | 76.2 | 0.47 |
|         | 1261.08 | 0.09 | 67.71 | 0.09 | 1260.91 | 0.04 | 77.28 | 0.51 |
|         | 1883.16 | 0.06 | 67.71 | 0.09 | 1883.37 | 0.04 | 62.76 | 0.19 |

## 4. Conclusions and Outlook

The aim of this work was to determine the half-lives and the spectra of Ga isotopes through photonuclear reaction. In this process, the electrons were absorbed by a tungsten converter inside the c-Linac and a photon beam from a c-Linac with endpoint energy of 18 MeV was obtained. The bremsstrahlung photons with this energy are sufficiently energetic to achieve photonuclear reactions with a Ga target. As a result, several energy transitions of different isotopes showing different half-lives were observed. The energies have shown a good agreement with literature date. However, the half-lives are determined less accurately as expected due to multi-isotope nature of our sample. The particularly interesting point of this experiment is the study of the suitability of a medical linac, used differently from previous studies.

## Acknowledgements

We acknowledge the financial support of the Scientific and Technological Research Council of Turkey (TÜBİTAK) with a project grant number 114F220 and Cumhuriyet University Scientific Project Unit with a project number SHMYO-007.

## References

[1] Belyshev S S et al 2014 NIM A 745 133
[2] Oka Y Kato T Nomura K and Saito T 1967 Journal of Nuclear Science and Technology 4 346
[3] Boztosun I et al 2014 Turk. J. Phys 38 1
[4] ORTEC 2012 Maestro Application Software
  [http://www.ortec-online.com/download/MAESTRO.pdf](http://www.ortec-online.com/download/MAESTRO.pdf)
[5] Radford D C 2000 Notes on the use of the program gf3
  [http://radware.phy.ornl.gov/gf3/gf3.html](http://radware.phy.ornl.gov/gf3/gf3.html)
[6] McCuthan E A 2012 Nuclear Data Sheets 113 1735: Tuli J K 2004 Nuclear Data Sheets 103 389