# Measurement of thick-target yields for the $^{64}Zn(\alpha,\gamma)^{68}Ge$ and $^{63}Cu(\alpha,\gamma)^{67}Ga$ reactions

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The calculation of thermonuclear reaction rates in quasi-static or explosive stellar environments is important [1] for the prediction of elemental synthesis. Charged-particle capture reactions for some *p*-process nuclei heavier than iron are useful for studying the nucleosynthesis process [2]. Thick-target yields are used for astrophysical thermonuclear reaction rate derivations [3,4], for studying the production of $^{26}Al_{g.s.}$, $^{7}Be$, etc. [5,6] and also for cross section measurements [7,8]. At sub-coulomb barrier energies, where charged-particle cross sections are usually very low, thick-target yield measurements can provide useful data on various important nuclear reactions. In this work, thick-target yields for the $^{64}Zn(\alpha,\gamma)^{68}Ge$ reaction in the 7- to 14-MeV energy range and $^{63}Cu(\alpha,\gamma)^{67}Ga$ at 7-MeV bombarding energy are measured and compared with the theoretical predictions. The theoretical yield is calculated numerically from the energy dependent theoretical cross section from Ref. [9].

Natural targets of zinc and copper of about ~0.06 inch thickness were mounted on the copper block one at a time for irradiations with different $He^+$ beam energies at the 88-inch cyclotron, Lawrence Berkeley National Laboratory (LBL). Samples were counted for $\gamma$-rays using the HPGe spectroscopy system at the Low Background Facility (LBF) after a suitable cooling time. The product activity of the $^{68}Ge$ radioisotope was determined by measuring the $\gamma$-rays from the daughter $^{68}Ga$ radioisotope under a secular equilibrium since $^{68}Ge$ emits no $\gamma$-rays.

The thick-target yield, *Y(E)*, for a full beam fully stopped in the target is determined using the following equation and corrected for pure isotopic targets:

$$Y(E) = n\int_0^E \frac{\sigma(E^{/})}{(-dE^{/}/dx)}dE^{/} = \frac{A_o}{\phi(1-e^{-\lambda t})} \qquad (1)$$

where $E$ is the bombarding energy, $\sigma(E^{/})$ is the energy dependent cross section, $dE^{/}/dx$ is the stopping power, and $n$ is the number of target nuclei; $A_o$ is the activity of the product radioisotope at the end of irradiation, $\varphi$ is the number of $He^+$ particles per second, $\lambda$ is the decay constant and $t$ is the irradiation time.

The calculated thick-target yields were obtained using the mid part of equation (1). Successive thin slices of 1000 Å thicknesses were considered in the thick target. The incident energy on each of the successive slices was calculated based on dE/dx, and the corresponding cross section was taken from a smooth fit made to the theoretical data from Ref. [9]. The consideration of the conceptual target slices continued until the incident beam energy reached zero. The number of target nuclei, *n*, was calculated for the 1000 Å thickness using the Avogadro's number, elemental mass, and considering 100% isotopic abundance in the target.

A portion of the γ-ray spectrum related to the $^{64}Zn(\alpha,\gamma)^{68}Ge$ is shown in Fig. 1. The measured and calculated thick-target yield for the $^{63}Cu(\alpha,\gamma)^{67}Ga$ reaction at 7-MeV bombarding energy is found to be $2.2\times10^{-9} \pm 0.2\times10^{-9}$ and $3.2\times10^{-9}$, respectively. The measured and calculated thick-target yields for the $^{64}Zn(\alpha,\gamma)^{68}Ge$ reaction are presented in Fig 2. All results were found to be mutually consistent, and they also follow the overall trend for the experimental and theoretical cross section data in the literature.

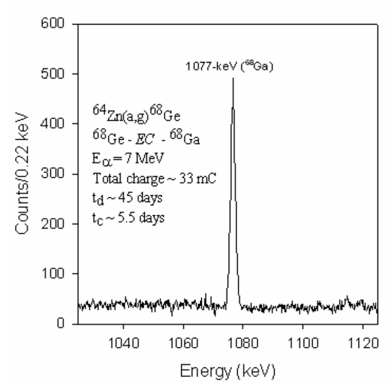


FIG. 1: A partial γ-ray spectrum shows a γ-line from $^{68}Ga$.

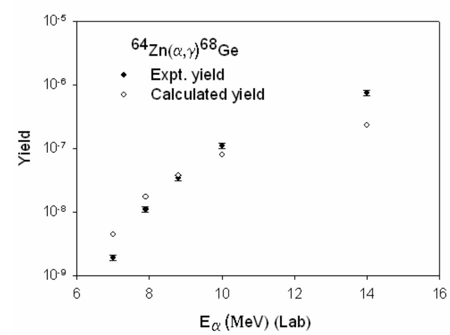


FIG. 2: Measured and calculated thick-target yields for the $^{64}Zn(\alpha,\gamma)^{68}Ge$ reaction.

## REFERENCES

[1] W. A. Fowler *et al.*, Ann. Rev. Astrophys. 13, 69 (1975).

[2] R. D. Hoffman *et al.*, Astrophys. J. 482, 951 (1997).

[3] N. A. Roughton *et al.*, At. Data Nucl. Data Tables 23, 177 (1979).

[4] N. A. Roughton *et al.*, At. Data Nucl. Data Tables 28, 341 (1983).

[5] N. P. T. Bateman *et al.*, Phys. Rev. C 57, 2022 (1998).

[6] C. M. Layman *et al.*, Phys. Rev. C 53, 1977 (1996).

[7] E. B. Norman *et al.*, Astrophy. J., 251, 834 (1981).

[8] F. K. McGowan *et al.*, Phys. Rev. 133, B907 (1964).

[9] T. Rauscher and F-K. Thielemann, At. Data Nucl. Data Tables 79, 47 (2001). URL: http://quasar.physik.unibas.ch/~tommy/nosmo.html.