Alpha-Induced Production Cross Sections of $^{77,79}$Kr and $^{77}$Br

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Alpha-Induced Production Cross Sections of $^{77,79}$Kr and $^{77}$Br

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Abstract. The production cross sections of $^{77,79}$Kr and $^{77}$Br following the $\alpha$-irradiation of natural selenium were determined between the $\alpha$-energies of 11 MeV and 15 MeV using the activation technique. The irradiation of natural selenium targets with He$^{2+}$ ions extracted from a cyclotron was conducted at Physikalisch-Technische Bundesanstalt in Braunschweig in Germany. The spectroscopic analysis of the reaction products was performed using a HPGe detector. As the $\alpha$-beam was stopped inside the targets, the thick target yields were determined. The corresponding energy-dependent cross sections were calculated from the difference of the thick target yields at various beam energies. The determined values were compared to theoretical predictions based on the TALYS code.

1. Motivation
Measurements of reaction cross sections help to constrain models predicting stellar reaction rates and can therefore improve our understanding of the stellar nucleosynthesis. The $\alpha$-induced production cross sections of the isotopes $^{77,79}$Kr and $^{77}$Br (Figure 1) help to understand the chemical evolution of the universe.

![Diagram showing the production of $^{77}$Kr via the $^{74}$Se($\alpha$,n) reaction, $^{79}$Kr via the $^{76}$Se($\alpha$,n) reaction and $^{77}$Br via the $^{74}$Se($\alpha$,p) reaction.](image)

**Figure 1.** Excerpt of the charts of nuclides showing the production of $^{77}$Kr via the $^{74}$Se($\alpha$,n) reaction, $^{79}$Kr via the $^{76}$Se($\alpha$,n) reaction and $^{77}$Br via the $^{74}$Se($\alpha$,p) reaction.
2. Selenium Target Production
The selenium targets for the activation at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany [1], were produced via the irradiation of a stable metallic $^{82}$Se sample by a He-beam. As the planned $\alpha$-beam were entirely stopped in the target material, a thick target layer was produced by melting selenium onto an aluminium backing. In total, nine backings with a diameter of 35 mm and a thickness of 1.5 mm and a gap in the middle with a diameter of 10 mm and a height of 0.5 mm were produced (Figure 2).

![Figure 2. Geometry of the selenium backings used for the irradiation at PTB in Braunschweig.](image)

Selenium powder was placed in the gap and heated in an oven to its melting point of 221°C. Because of the high surface tension of selenium, the powder did not melt smoothly, but built droplets. These were spread mechanically using a spattle after reducing the oven temperature at approximately 100°C. More selenium powder was put in the gap as a part of it stick on the spattle. The heating procedure was repeated to form a smooth layer of selenium, which is essential for an activation experiment.

3. Experiment at Physikalisch-Technische Bundesanstalt
The prepared selenium targets were activated in February 2014 at the PTB in Braunschweig, Germany, and irradiated at the energy-variable PTB cyclotron [2]. Doubly-charged He ions were extracted from the cyclotron to irradiate the targets in the activation chamber designed as a Faraday cup [2]. A wobbled $\alpha$-beam was used to increase the size of the illumination spot on the targets. A water cooling system was used to reduce the target temperature. In total, nine samples were irradiated at different $\alpha$-energies between 11 MeV and 15 MeV.

Krypton stays trapped in selenium as long as the temperature stays below 50°C [3], so the temperature during the irradiation had to stay below this temperature. For this reason, four activations were performed to test the thermal stability of selenium. The currents of $I = 4 \mu$A and $I = 1 \mu$A led to selenium losses, hence a current of $I = 500$ nA was found to be appropriate for the irradiations. Five activations with activation times between 0.5 h and 6.8 h were performed. The spectroscopic analysis of the reaction products $^{77,79}$Kr and $^{77}$Br was conducted using a High Purity Germanium (HPGe) detector at PTB in Braunschweig.

4. Results
As the $\alpha$-beam was stopped inside the targets, the thick target yields were determined. The corresponding energy-dependent cross sections at the $\alpha$-energies of 12 MeV and 14 MeV were calculated from the difference of the thick target yields at various energies:

$$\sigma(E_1, E_2) \propto Y_{\text{thick}}(E_2) - Y_{\text{thick}}(E_1).$$ (1)
The resulting preliminary $\alpha$-induced production cross section of $^{77}$Kr at an $\alpha$-energy of 12 MeV is 160 mb and at an $\alpha$-energy of 14 MeV 400 mb. The $\alpha$-induced production cross section of $^{77}$Br at an $\alpha$-energy of 12 MeV is 62 mb and at an $\alpha$-energy of 14 MeV 120 mb. The $\alpha$-induced production cross section of $^{79}$Br at an $\alpha$-energy of 12 MeV is 250 mb and at an $\alpha$-energy of 14 MeV 400 mb.

Figure 3. The $\alpha$-induced production cross sections of $^{77,79}$Kr and $^{77}$Br at 12 MeV and 14 MeV compared to the theoretical predictions of TALYS-1.6. The energy uncertainty of ±1 MeV originates from the subtraction of the thick target yields.

Finally, the resulting values of the $\alpha$-induced production cross sections were compared to theoretical predictions based on the TALYS-1.6 code [4]. The theoretical predictions were found to be in a good agreement with the measured cross sections (Figure 3).

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