The Reaction ^{70}Ge(α,γ)^{74}Se (p–process)

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The cross section of the reaction ^{70}Ge(α,γ)^{74}Se is measured in the bombarding energy range of 4.90<E_α<7.53 MeV. The experimental S–factor values are in good agreement with theoretical calculations. Reaction rates for the inverse (γ,α) reaction are determined.

INTRODUCTION

The stable neutron–deficient isotopes of the elements with charge number Z$\geq$ 34 are classically referred to as the p–nuclei. They were observed only in the solar system and here they represent 0.1% to 1% of the bulk elemental abundances, made predominantly of the more neutron–rich s– and r–nuclei. The stellar process synthesizing the p–nuclei is called the p–process. Several models have been developed for describing the p–process (1–3). There are differences in the details (astrophysical site, temperature, time scale, reactions involved, etc.), however, the generally accepted main process are subsequent (γ,n) reactions, which start from s– and r–nuclei and drive the nuclei towards the neutron–deficient region. Along this isotopic path, the binding energy of neutrons is gradually larger. As a result, the reaction flow slows down and, at some point, is deflected by (γ,α) or (γ,p) reactions. At these branching points the matter tends to accumulate. The branching points are the p–nuclei themselves (light ones) or their progenitors (heavy ones). In fact, (n,γ) reactions can be also important and compete with photon–induced reactions.

Above Si, theoretical p–process studies (4,5) have to rely mainly on reaction rates predicted in the framework of the statistical model. For charged particle reactions practically no experimental data is available above the Fe region.

Of crucial importance is the investigation of the branchings. The first candidate is ^{74}Se, the lightest p–nucleus (lowest Coulomb barrier) sitting at such a branching point. Here, the ejection of an alpha particle is favoured relative to the protons (3). Up to now, the ^{70}Ge(α,γ)^{74}Se reaction has been investigated for energies $E_\alpha > 12$ MeV (6), i.e. above the Gamow window, Coulomb barrier and neutron threshold.

EXPERIMENTS AND RESULTS

The experiment on the ^{70}Ge(α,γ)^{74}Se reaction has been performed at the cyclotron in Debrecen and the Dynamitron Tandem accelerator in Bochum from E_α=4.9 MeV up to 7.8 MeV (E_{cm}=4.635–7.378 MeV), using a He^{++}–beam. In the first run, with the target on thick backing, only one gamma–transition from ^{74}Se, namely the decay of the first excited state to the ground state (E_γ=635 keV) was seen. However, the yield was low and the background was very high. High beam current, long measuring time and improved detection efficiency are necessary to compensate the small reaction cross section. For reducing the background yield (predominantly caused by high energy gamma-rays and neutrons from the ^{13}C(α,n)^{16}O reaction) the thick Ta backing —which integrates the background yield— was replaced by a thin (0.1 μm) gold foil. With this it was not possible to use a high beam current. However, the reaction yield to background ratio improved. The resulted loss in yield has been compensated by using a high efficiency Ge detector (116% HPGe) in close geometry and the background has been further lowered by the proper choice of geometry and shielding. An enriched (86.5%) ^{70}Ge target was used with an averaged target current of 500 particle–nA, avoiding any target deterioration. The target stability was monitored by the strong Coulomb excitation peak of the ^{70}Ge target nucleus (1040 keV). Because of the increased yield to background ratio not only the peak at E_γ=635 keV but also others from ^{74}Se have appeared in the spectrum taken with relatively good statistics at E_{cm}=6.514 MeV, namely the E_γ=985 keV and 219 keV ones belonging to a cascade going through the first excited state. In the same spectrum very weak primary transitions to the ground and first excited states have also appeared. The total cross section of the ^{70}Ge(α,γ)^{74}Se reaction was determined using only the intensity of the E_γ=635 keV peak. In principle this is only a lower limit, however, in the spectra all the peaks mentioned above belonging to the decay of ^{74}Se represent transitions decaying directly or after a few steps through the first excited state to the ground state. The only exception is the extremely weak (see later) primary transition to the ground state. It is clearly demonstrated by these experimental facts (see also Ref. (6)) together with a statistical survey of the decay of the known 53 levels in ^{74}Se (7) (which shows that more than 90% of all the decays —as an average— go through the first excited state), that the 635 keV peak represents the total cross section (within the error limit). To convert the peak area to the cross section, the absolute efficiency of the detector was measured, and the number of target atoms/cm^2 has been determined by the RBS technique. The E_γ=635 keV transition is fed by more transitions, therefore no correction for angular distribution is necessary. The errors of the resulted cross sections vary between 10 and 40% (except at the lowest energy).

The measured cross sections are in excellent agreement with the statistical model calculation performed with the code SMOKER (5). We used the most recent mass table (8) giving a Q-value of 4.077 MeV. The measured and cal-

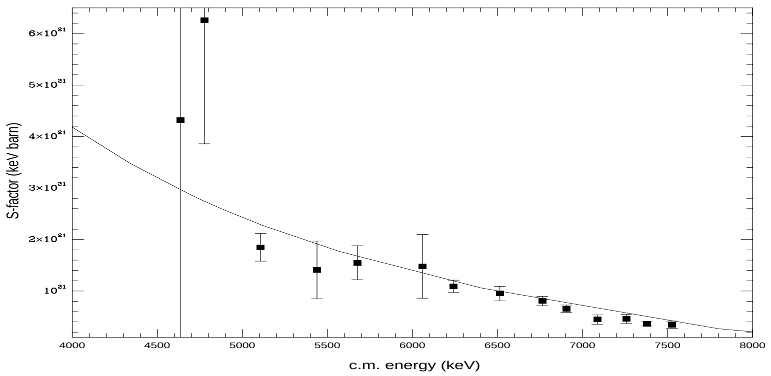

FIG. 1. The S–factor of the reaction ^{70}Ge(α,γ)^{74}Se from the transition between the first excited state (E_x=6438 keV; J^π=2$^+$) and ground state of the residual nucleus.

culated S–factors are shown in Fig. 1. With the help of additional theoretical values at low energies we calculated reaction rates for the forward (capture) reaction as well as for the inverse (photodisintegration) reaction using detailed balance (9). The rates for thermally excited targets are given in Table 1, as well as the ratio of the rate factors. The experimental data contribute to the rates significantly only for $T_9 \geq 1.0$.

The possible contribution of the direct process has also been calculated and was found being negligible.

For the mentioned primary transitions, the cross sections at E_{cm}=6.514 MeV are: σ=1.0$\pm$0.6 μbarn and 2.0$\pm$0.7 μbarn to the ground state and first excited states, respectively. The values are close to our detection limits and negligible (here the error of the total cross section itself is 23 μbarn).

The work is in progress, the future tasks are to improve the statistics, to perform coincidence measurements for identifying the peaks connected to the 635 keV transition on a reduced background and to determine the cascade corrections.

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TABLE 1. Stellar reaction rates for ^{70}Ge(α,γ) and the inverse reaction.

Temperature 10^9 K	$N_A < \sigma v >_\alpha$ [cm^{3}s^{-1}mole^{-1}]	$< \sigma v >_\gamma$ [cm^{3}s^{-1}]	$\frac{<\sigma v>_\alpha}{<\sigma v>_\gamma}$
0.50	4.36×10^{-29}	9.06×10^{-60}	7.99×10^{6}
0.60	8.87×10^{-26}	1.71×10^{-49}	8.61×10^{-1}
0.70	3.82×10^{-23}	7.24×10^{-42}	8.76×10^{-6}
0.80	5.59×10^{-21}	6.04×10^{-36}	1.54×10^{-9}
0.90	3.74×10^{-19}	3.44×10^{-31}	1.81×10^{-12}
1.00	1.38×10^{-17}	2.84×10^{-27}	8.06×10^{-15}
1.50	4.17×10^{-12}	1.08×10^{-14}	6.43×10^{-22}
2.00	1.07×10^{-8}	1.04×10^{-7}	1.71×10^{-25}
2.50	2.50×10^{-6}	3.45×10^{-3}	1.20×10^{-27}
3.00	1.36×10^{-4}	5.13×10^{0}	4.40×10^{-29}
3.50	2.83×10^{-3}	1.14×10^{3}	4.12×10^{-30}
4.00	3.05×10^{-2}	7.48×10^{4}	6.78×10^{-31}
4.50	2.04×10^{-1}	2.09×10^{6}	1.62×10^{-31}
5.00	9.48×10^{-1}	3.19×10^{7}	4.94×10^{-32}
6.00	9.15×10^{0}	1.98×10^{9}	7.67×10^{-33}
7.00	4.26×10^{1}	3.74×10^{10}	1.89×10^{-33}
8.00	1.24×10^{2}	3.17×10^{11}	6.49×10^{-34}
9.00	2.65×10^{2}	1.56×10^{12}	2.83×10^{-34}
10.00	4.53×10^{2}	5.13×10^{12}	1.47×10^{-34}

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