Measurement of absolute cross-sections for alpha induced reactions on $^{112,114,118}Sn$

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Introduction

The p-process of stellar nucleosynthesis is aimed at explaining the production of the stable proton-rich nuclei heavier than iron that are observed up to now in the solar system exclusively. Various scenarios have been proposed to account for the bulk p-nuclide content of the solar system, as well as for anomalies with respect to the bulk p-isotope composition of some elements discovered in primitive meteorites [1]. There are differences in the details (astrophysical site, temperature, time scale, reactions involved, etc.), however, the generally accepted main process involves sequential (γ,n) reactions starting from s and r-nuclei and driving the nuclei towards the proton rich region [2–4]. Along this isotopic path, the binding energy of neutrons becomes gradually larger, the reaction flow slows down and, at some point in a chain of isotopes, (γ,p) and/or (γ,α) reactions will become faster than the neutron emission, and the flow will branch and feed another isotopic chain. With decreasing temperature, the photodisintegrations become less effective, leading to a shift of the branch points and a takeover of β^+ decay. At the end of the process, photodisintegrations cease quickly, and the remaining unstable nuclei will decay back to stability.

The effectiveness of neutron emission is governed by the neutron separation energies and will decrease for increasingly proton-rich nuclei. Similar considerations apply for proton and α emission except that for emission of charged particles an additional exponential dependence on the Coulomb barrier enters the cross section. Therefore, for comparable separation energies, neutron emission will occur fastest, and proton emission will dominate α emission. Because of the evolution of the separation energies, there will be a nucleus within each isotopic chain, for which charged particle emission occurs faster than neutron emission. This is the branch point according to the definition given above [2]. Thus the branching established by the dominance of proton and/or alpha emission over neutron emission is crucial in determining the radioactive progenitors of the stable p-nuclei. The absolute values of the rates determine the dynamics and time scales, which also depend on the time-dependent temperature profile and thus on the chosen astrophysical scenario. The branching themselves depends only on the ratios of the involved reaction rates. When rates are comparable the actual value of the cross sections is also important. Cross sections of nuclei relevant for the p-process can be calculated with the statistical Hauser-Feshbach model because the level densities at the effective excitation energies are sufficiently high to average over resonances. Thus, sensitive branching will also depend on the nuclear properties entering the statistical model. Among those, the transmission coefficients for charged particles computed with the optical model will be the most important ones, especially when dealing with projectile energies close to the Coulomb barrier, as is the case for the p-process.

Scientific motivation

Only rather recently charged particle induced reaction rates at p-process energies (Ep ~ 1–10 MeV, Eα ~ 5–15 MeV) became subject of experimental efforts [4]. For example, a series of α -scattering experiments at energies below the Coulomb barrier helped to improve the optical α -nucleus potential [4-8], but firm conclusions are still difficult to draw due to the lack of experimental cross sections. Consequently, extrapolations to the low astrophysical energies remain necessary. On the other hand, scattering data within a confined energy range can be described equally well by different optical potentials with different extrapolation behavior and this ambiguity makes extrapolations very uncertain [9-12]. These uncertainties can be avoided if experimental cross sections are available for comparison with HF predictions in or close to the astrophysical Gamow window. For the (α,γ) case, one of the main problems for the calculation of reaction rates is the determination of the optical α-nucleus potentials at low energies. The experimental studies indicate deviations of up to one order of magnitude of the HF predictions for α-capture and their inverse photodisintegration processes [2]. Therefore, it is very important to investigate the charged particle induced reaction cross sections experimentally in order to diminish as much as possible these discrepancies.

The reactions on tin isotopes are good test candidates for the statistical model assumptions in the stellar process energy range because the level density decreases at closed shells. Up to now, in the literature, are two different experimental data sets of α-induced cross section on ^{112}Sn [13,14], and our previous measurements on ^{117}Sn [15], and ^{115,116}Sn [16]. Because extended experimental cross section data on an isotopic chain give a higher reliability in using global optical model parameterizations, we decide to focus on the tin isotopic chain. Namely, we propose to re-measure the α-induced cross section on ^{112}Sn because of the discrepancies between the existent data sets and to measure for the first time the α-induced cross sections on ^{114}Sn and ^{118}Sn.

<u>Proposed experiment</u>

For each isotope, ^{112}Sn, ^{114}Sn, and ^{118}Sn, we propose to measure the absolute cross sections of the reactions induced by alphas at 5 different energies ranging from 8.5 to 16 MeV using the activation method. For incident beam energy, the target stack having five tin layers alternating with aluminum foils will be irradiated using the scattering chamber mounted on the beam line #5 and, after that, its decay spectra will be measured off-line with a specially designed low-background setup consisting into a pair of large volume HPGe detectors surrounded by Pb walls clothed with Cu and Al plates on the inside. The HPGe detectors of about 50% will be mounted in close-to-detection geometry in order to maximize the detection efficiency. The absolute cross sections for each reaction populating a certain decaying nucleus will be extracted from the peak areas of the corresponding characteristic γ-rays.

<u>Beam time request</u>

We want to measure α-induced cross sections on three tin isotopes at five energies each (one stack of five target foils). For one isotope we ask 2 days for irradiations and 5 days

(one day per target foil) for measuring the induced characteristic activation. Therefore, we ask for 7 days beam time for isotope, which give a total of 21 days beam time or three different periods of 7 days beam time. Obviously we would prefer, if possible, the last variant.
The alpha beam should have at least an intensity of 50 nA, kept constant as much as possible, thus allowing a precise extraction of the absolute cross sections.

Bibliografie:

[1] M. Arnould and S. Goriely, Phys. Rep. 384, 1 (2003).
[2] W. Rapp, J. Görres, M. Wiescher, H. Schatz, and F. Käppeler, Astrophys. J. 653, 474 (2006).
[3] KADoNiS, The Karlsruhe Astrophysical Database of Nucleosynthesis in Stars, http://www.kadonis.org.
[4] P. Demetriou, C. Grama, and S. Goriely, Nucl. Phys. A707, 253 (2002).
[5] M. Avrigeanu, W. von Oertzen, A. J. M. Plompen, and V. Avrigeanu, Nucl. Phys. A723, 104 (2003).
[6] Z. Fülöp, G. Gyürky, Z. Máté, L. Somorjai, E. Zolnai,D. Galaviz, M. Babilon, P. Mohr, A. Zilges, T. Rauscher,H. Oberhummer et al., Phys. Rev. C 64, 065805 (2001).
[7] T. Rauscher, Nucl. Phys. A719, 73 (2003).
[8] T. Rauscher, Erratum, Nucl. Phys. A725, 295 (2003).
[9] P. Mohr, T. Rauscher, H. Oberhummer, Z. Máté, Z. Fülöp, E. Somorjai, M. Jaeger, and G. Staudt, Phys. Rev. C 55, 1523 (1997).
[10] L. McFadden and G. Satchler, Nucl. Phys. 84, 177 (1966).
[11] Z. Fülöp, A. Z. Kiss, E. Somorjai, C. E. Rolfs, H.-P. Trautvetter, T. Rauscher, and H. Oberhummer, Z. Phys. A 355, 203 (1996).
[12] D. Galaviz, Z. Fülöp, G. Gyürky, Z. Máté, P. Mohr, T. Rauscher, E. Somorjai, and A. Zilges, Phys. Rev.C71, 065802 (2005).
[13] N. Özkan et al., Phys. Rev. C 75, 025801 (2007).
[14] W. Rapp et al., Phys. Rev. C 78, 025804 (2008).
[15] Cata-Danil et al., Phys. Rev. C 78, 035803 (2008).
[16] D. Filipescu, et al., Phys. Rev. C **83** (2011) 064609.