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# ASTROPHYSICAL IMPLICATIONS OF CHARGED PARTICLE EMISSION REACTIONS INDUCED BY SLOW NEUTRONS

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ABSTRACT. Results of statistical model calculations for average (n,α) cross sections are compared with experimental values at E=30 keV. Using the results of theoretical calculations for the (n,α) and (n,p) cross sections were proposed new measurement for nuclear astrophysics study on the IREN neutron source projected at the Frank Laboratory of Neutron Physics, JINR, Dubna.

## 1. INTRODUCTION

Results of study (n,α) and (n,p) reactions induced by slow neutrons (E<1MeV) can be used for the nuclear astrophysics. In particular, cross sections of these reactions around 30 кeV neutron energy, corresponding to temperatures of $3.5\cdot10^{8}$ K, as they are typical for helium burning in red giant stars, can be used to calculate thermonuclear reaction rate and the strength of the s-process (slow neutron capture) branching [1]. In turn, these informations are used, for example, in calculation of the heavy elements synthesis during the big bang. However, experimental data base of these reactions is rather sparse and there are significant discrepancies between the available results of various authors. In the energy range of slow neutrons the charged particle emission reactions measurements are difficult because of low cross sections and is required the use of a high flux neutron source and a high luminosity charged particle spectrometer.

For measuring angle and energy distributions of secondary charged particles have been developed various types of detectors having large geometrical efficiency and low background (see, for example, ref.[2,3]). On the other hand, in 1994 at the Frank Laboratory of Neutron Physics, JINR, Dubna, was proposed a new intense, resonance neutron source, IREN [4], optimized for investigations in the resonance neutron energy range. Realization of the IREN project would promote widening of collaboration in neutron-nuclear physics between research institutions of the JINR member-states. Because of this, in order to propose a new research project on the IREN source, in this paper is reported on our some consideration for nuclear astrophysics investigation.

## 2. COMPARISON OF THEORETICAL MODEL CALCULATIONS WITH EXPERIMENTAL (n,α) CROSS SECTIONS

In order to calculate slow neutron induced average (n,α) cross sections we have suggested a working formula based on the statistical model [5]. Our results of the statistical model calculation and experimental values for average (n,α) cross sections at E~30 кeV in comparison with

theoretical calculation by Holmes et al. [6] are given in Table 1. Table 1 shows that results of the theoretical model calculations are satisfactorily in agreement with experimental values.

Table 1. Theoretical and experimental (n,α) cross sections at E~30 keV for several heavy nuclei

| Target Nuclei | (n, α) cross section, μb | | |
|---|---|---|---|
| | $\sigma_{exp}$ | $\sigma_{calc.}$ [this work] | $\sigma_{calc.\ [6]}$ |
| $^{95}$Mo | 20 ± 4<br>[7] | 16 | 18.7 |
| $^{123}$Te | 2.8 ± 0.7*<br>[8] | 4 | 2.9 |
| $^{143}$Nd | 20 ± 3<br>[9] | 28 | 23.8 |
| $^{147}$Sm | 28 ± 5<br>[9] | 15 | 32.1 |
| $^{149}$Sm | ≤ 6<br>[9] | 3 | 3.2 |

* - This value was measured at E=24.5 keV

## 3. ASTROPHYSICAL APPLICATIONS OF AVERAGE (n,α) CROSS SECTION

The quality of s-process calculation depends strongly on the three sets of input data: (1) stellar reaction rates of the nuclei on the synthesis path, (2) beta half-lives of unstable nuclei, and (3) s-process abundances [10]. The stellar reaction rate

$$\langle\sigma\upsilon\rangle = \int_0^\infty \sigma\upsilon\Phi(\upsilon)d\upsilon \qquad (1)$$

is determined by integration over the velocity distribution $\Phi(\upsilon)d\upsilon$ of neutrons. On the other hand, the strength of the s-process branching is determined by the rates for beta decay,

$$\lambda_\beta = \frac{\ln 2}{T_{1/2}} \qquad (2)$$

and for neutron reaction,

$$\lambda_n = \langle\sigma\rangle\cdot n_n\cdot V_T, \text{ as} \qquad (3)$$

$$f_n = \frac{\lambda_n}{(\lambda_n + \lambda_\beta)}, \qquad (4)$$

where $n_n$ is the stellar neutron density; $V_T$ is the mean thermal velocity. Average stellar neutron cross section, <σ>, can be determined as

$$\langle\sigma\rangle = \langle\sigma_{n\gamma}\rangle + \langle\sigma_{n\alpha}\rangle + \langle\sigma_{np}\rangle \qquad (5)$$

From here it can be seen that the (n,α) and (n,p) cross sections play an important part in processes of stellar nucleosynthesis. Reciprocal influence of various nuclear processes for the mass region 143<A<150 is illustrated in Fig.1.

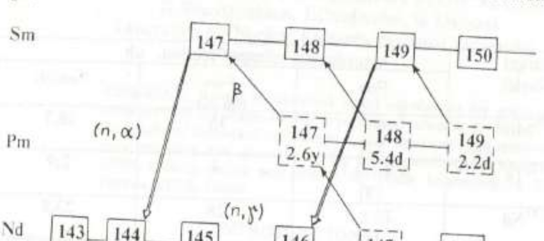

Fig.1. The nuclear astrophysics processes in the mass region 143<A<150. Branch points are indicated by dotted boxes

It should be noted that $^{148}$Sm and $^{150}$Sm are the s-only isotopes. Because of low cross sections the (n,α) reactions perhaps are not important in comparison with (n,γ) and other processes in the stellar nuclear process displayed in Fig.1 (see Table 1). However, there is a number of the stable and radioactive isotopes which have considerable (n,α) cross section for slow neutrons.

## 4. CALCULATED CROSS SECTIONS FOR MEASUREMENT ON THE IREN SOURCE

Results of the statistical model calculations of (n,α) and (n,p) cross sections for some stable and radioactive isotopes which can be measured on the IREN source are given in Table 2.

Table 2. Calculated (n,α) and (n,p) cross sections

| № | Target nuclei | Abundance or $T_{1/2}$ | Type of reaction | Q-value (MeV) | $\sigma_{calc}$ (mb) at 30keV |
|---|---|---|---|---|---|
| 1 | $^{26}$Al | $7.2\cdot10^5$ y | (n,p) | 4.79 | 600 |
| 2 | $^{33}$S | 0.75% | (n,α) | 3.49 | 180 |
| 3 | $^{36}$Cl | $3.0\cdot10^5$ y | (n,p) | 1.93 | 170 |
| 4 | $^{37}$Ar | 35.04 d | (n,α) | 4.63 | 560 |
| 5 | $^{91}$Zr | 11.2% | (n,α) | 5.66 | $4\cdot10^{-3}$ |
| 6 | $^{96}$Ru | 5.52% | (n,α) | 6.38 | $15\cdot10^{-3}$ |
| 7 | $^{99}$Ru | 12.7% | (n,α) | 6.82 | $20\cdot10^{-3}$ |

It would be noted that our results are of preliminary and will be continued more detail calculations for astrophysical applications.

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# УСТӨРӨГЧЖҮҮЛСЭН АМОРФ ЦАХИУРЫГ УУГИХ ЦАХИЛАЛТАНД ГАРГАН АВАХ ТӨХӨӨРӨМЖ

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## 1.ОРШИЛ

Устөрөгжүүлсэн аморф цахиурыг /a-Si:H/ электроникийн материал болгон өргөн хэрэглэж болж байгаа болон уг материалын шинж чанарын судалгаатай уялдан түүнийг гарган авах хэд хэдэн арга хэрэглэж байна. Эдгээр аргуудаас уугих цахилалтын арга /Glow Dischage/, цахих арга /Sputtering/, химийн ууршуулалтын арга /CVD/ зэрэг нь өргөн хэрэглэгдэж байна. Аморф цахиур гарган авах төхөөрөмжинд тавигдах гол шаардлага хольцолж болохуйц дээж гарган авах явдал юм. Үүнийг аморф цахиурын хувийн дефект болох тасархай холбоосыг саармагжуулах элементийг хамт хэрэглэсиээр шийдвэрлэж болдог. Ийм үүргийг устөрөгчийн атом гүйцэтгэж чаддаг учир /a-Si:H/ гарган авахдаа эсвэл устөрөгчтэй орчинд эсвэл устөрөгчтэй орчинд эсвэл устөрөгч агуулсан материал ашигладаг юм.

Уугих цахилалтын арга: Цахилгаан орны тусламжтай үүсэж буй плазмаар силан хийг задалж 200-300°C температурт халаасан суурин дээр /a-Si:H/ хальсыг суулгах арга. Энэ аргаар гарган авсан материалын локаль төлвийн нягт бага байдаг учир электроникийн материалд тавигдах үндсэн шаардлагууд хангагддаг. Иймд судалгаанд зориулсан материал гарган авахад энэ аргыг өргөн хэрэглэж байна. Мөн хэрэглэж буй хийн найрлагыг өөрчилснөөр өөр өөр үе гарган авч болдогт энэ аргын нэг давуу тал оршино.

Цацах арга: Энэ нь уугих цахилалтын аргатай үндсэндээ төстэй юм. Ионоор бөмбөгдүүлж буй цахиур хавтанг материалын үүсгүүр болгон ашигладаг. Сул болсон цахиурын атомууд плазмын тусламжтайгаар халаасан суурь руу зөөгдөнө. Энэ аргын хувьд ургалтын хурд харьцангуй их учир үйлдвэрлэлд давуу хэрэглэнэ.

CVD-арга: Устөрөгчөөр шингэлсэн силаныг өндөр температурын орчинд химийн урвалаар задалж /a-Si:H/ гарган авдаг. Хэрхэн химийн урвал явуулж байгаагаас хамааран фото-CVD, термо-CVD, гомо-CVD гэж ангилдаг. Бид эдгээр аргаас уугих цахилалтын аргыг сонгон авч, судалгаанд хэрэглэж болохуйц дээж гарган авах боломжтой лабораторийн төхөөрөмж зохион бүтээж хийх зорилт тавьсан юм.

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