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Investigation of the D(^{3}He, p)^{4}He reaction in the astrophysical energy region of 18 ÷ 30 keV

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1. Introduction. To study fusion reactions of "bare nuclei" D(d, p)^{3}H, D(d, n)^{3}He, T(d, n)^{3}He, ^{3}He(d, p)^{4}He, and D(^{3}He, p)^{4}He at astrophysical energies is of interest for both basic and applied physics [1]. These reactions participate in primordial nucleosynthesis. Information on the number of the D, T, ^{3}He, and ^{4}He nuclei formed in the early Universe is used to characterize baryon density in today's universe. In addition, these studied provide information on electron screening of nuclear reactions. To understand processes occurring in stars and quantitatively estimate their characteristics, the mechanism for screening interacting particles is investigated under the laboratory conditions. The screening is described by the screening potential U_e, which effectively decreases the Coulomb potential in the Gamow peak energy range [2].

Parameterization nuclear reaction cross sections in the form with the weakly energy-dependent astrophysical parameter $S(E)$

$$\sigma(E) = \frac{S(E)}{E + U_e} \exp(-2\pi\eta(E + U_e)) \qquad (1)$$

allows the reaction enhancement factor f to be defined in terms of the screening potential U_e. In particular, when $U_e \ll E$, the expression for f has a simple form

$$f = \exp\left(\frac{\pi\eta(E)U_e}{E}\right). \qquad (2)$$

Here we use the conventional designation of the Sommerfeld parameter η, the numeric value of which is conveniently written as $2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\mu/E}$ with the c.m.s. energy E in keV, reduced mass of the colliding nuclei μ in a.u.m., and charges of the colliding nuclei Z_1 and Z_2.

The goal of this work was to determine experimentally the electron screening potential U_e and the enhancement factor for the D(^{3}He, p)^{4}He reaction using a ZrD target.

2. Experiment. The experiment was carried out with deuterated metal targets produced by magnetron sputtering of zirconium in the deuterium medium. Distribution of deuterons over the target depth was measured by the Elastic Recoil Detection (ERD) technique using a beam of alpha particles with the energy of 2.3 MeV produced by van de Graaff accelerator at Joint institute for nuclear research [3].

The D(^{3}He, p)^{4}He reaction was investigated at the pulsed plasma Hall accelerator [4] (Tomsk) in the ^{3}He$^+$ ion energy range $E_{\mathrm{He}} = 18 \div 30$ keV ($E = 7.2 \div 12.0$ keV in the center-of-mass system) with a step of 2 keV. Protons with the energy of 14.7 MeV from the D(^{3}He, p)^{4}He reactions were detected by a scintillation detector based on the BC-404 scintillator 115 mm in diameter and 4 mm thick that was in optical contact with the XP-2040 PMT. The number of accelerated ^{3}He$^+$ incident on the zirconium deuteride target was $\sim 5 \cdot 10^{14}$ per pulse. The duration of the acceleration pulse was chosen to be 10 μs, which allowed detection of background events from cosmic radiation.

3. Processing of experimental data. Experimental results. The electron screening potential and the enhancement factor of the D(^{3}He, p)^{4}He reaction in zirconium deuteride at ultralow ^{3}He$^+$-deuteron collision energies are determined by measuring the yield of 14.7 MeV protons from this reaction and using the parametric dependence of the reaction cross section on the collision energy in the case of a "thick target" [4]

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$$N_p^{\text{calc}}(E_{\text{He}};U_e) = N_{\text{He}}\epsilon_p \int\limits_0^\infty F(E;E_{\text{He}})dE \times$$

$$\times \int\limits_0^E \sigma_{\text{Hed}}(E';U_e)N(x(E,E'))\left(-\frac{dE'}{dx}\right)^{-1} dE', \quad (3)$$

$N_p^{\text{calc}}(E_{\text{He}};U_e)$ is the calculated yield of protons from the Hed-reaction at the average energy of incident $^3\text{He}^+$ ions E_{He}, $\sigma_{\text{Hed}}(E',U_e)$ is the Hed-reaction cross section in parameterization (1), N_{He} is the number of $^3\text{He}^+$ ions that hit the target, ϵ_p is the proton detection efficiency, $n(x(E,E'))$ is the deuteron density in the target at the depth x determined by the particle energy E' at the initial energy of the incident particle E, $(-dE'/dx)$ is the specific loss energy of ^{3}He ions in the target, and $F(E;E_{\text{He}})$ is the distribution function of ^{3}He ions over the energy E at their average energy E_{He}.

Fitting (3) to the experimental on and natural environmental radioactivity to be suppressed by a factor of 10^5 proton yields $N_p^{\text{exp}}(E_{\text{He}})$ using the free parameter U_e gave the electron screening potential 617.8 ± 154.7 eV with $\chi^2 = 1.4$. The experimental enhancement factor $f_{\text{Hed}}^{\text{exp}}(E)$ is defined as

$$f_{\text{Hed}}^{\text{exp}}(E) = N_p^{\text{exp}}(E)/N_p^{\text{calc}}(E,U_e=0), \quad (4)$$

where $N_p^{\text{calc}}\ (E_{\text{He}},U_e=0)$ is the proton yield of the reaction calculated by Eq. (3) under the assumption that $U_e = 0$. Figure 1 shows the experimental enhancement factor $f_{\text{Hed}}^{\text{exp}}(E)$ and the model enhancement factor $f_{\text{Hed}}^{\text{calc}}\ (E)$ of the $\text{D}(^3\text{He},\text{p})^4\text{He}$ reaction calculated by Eq. (2) with the electron screening potential $U_e = 617.8$ eV.

The electron screening potential measured for the $\text{D}(^3\text{He},\text{p})^4\text{He}$ reaction is appreciably higher than the one measured with gas targets.

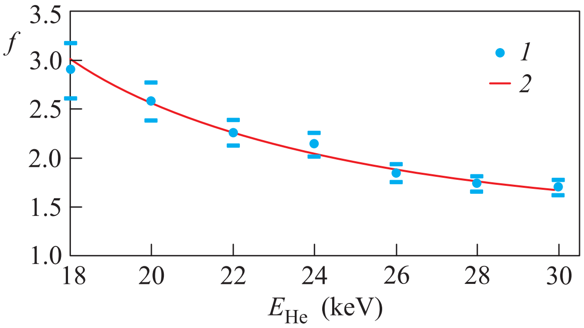

Fig. 1. (Color online) Experimental (*1*) and model (*2*) reaction enhancement factors

This discrepancy can be caused by the ZrD lattice effects, the role of which has not yet been studied either theoretically or experimentally.

The screening potential of the $\text{D}(^3\text{He},\text{p})^4\text{He}$ reaction is $U_e = 617.8$ eV, which increases the reaction yield by a factor three at the c.m.s. energy of 7.2 keV. This can be of interest for using this reaction in thermonuclear power production based on beam technologies.

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1. P. Navrátil and S. Quaglioni, Phys. Rev. Lett. **108**, 042503 (2012).
2. H. J. Assenbaum, K. Langanke, and C. Rolfs, Z. Phys. A **327**, 461 (1989).
3. A. P. Kobzev, J. Huran, D. Maczka, and M. Turek, Vacuum **83**, 124 (2009).
4. V. M. Bystritsky, Vit. M. Bystritskii, G. N. Dudkin, M. Filipowicz, S. Gazi, J. Huran, A. P. Kobzev, G. A. Mesyats, B. A. Nechaev, V. N. Padalko, S. S. Parzhitskii, F. M. Pen'kov, A. V. Philippov, V. L. Kaminskii, Yu. Zh. Tuleushev, and J. Wozniak, Nucl. Phys. A **889**, 93 (2012).