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NEW RESULTS FOR THE P-^{12}C RADIATIVE CAPTURE AT LOW ENERGIES

Abstract. New measurements of the differential cross sections of the ^{12}C(p,γ)^{13}N radiative capture reaction at the angle 0^0 for the transition to the ground state in ^{13}N have been made at the energies of incident protons from 1088 to 1390 keV (uncertainties of about 12%). Based on the obtained differential cross sections and on the assumption that the angular distributions are isotropic in this energy region, the ^{12}C(p,γ)^{13}N reaction astrophysical S-factors have been determined for the transition to the ground state in ^{13}N with an uncertainties of about 16%. Within the limits of uncertainties, our experimental results are consistent with the previous data. Analysis of the ^{12}C(p,γ)^{13}N reaction astrophysical S-factor at low energies has been carried out within the modified R-matrix approach by using previously measured asymptotic normalization coefficient of the overlap integral of the wave functions of ^{12}C and ^{13}N nuclei bound states to minimize the uncertainties due to calculation of the direct capture part of the ^{12}C(p,γ)^{13}N reaction astrophysical S-factor at extremely low energies. For the energies of 0.25 and 50 keV in center of mass frame the calculated values of the ^{12}C(p,γ)^{13}N reaction S-factors for the transition to the ground state in ^{13}N are presented. In the temperature range from 0 to 10^{10} K the rates of the ^{12}C(p,γ)^{13}N fusion reaction have been obtained. The results of our calculations are compared with the experimental and calculated results of previous works.

Keywords: differential cross sections, total cross sections, astrophysical S-factor, asymptotic normalization coefficient, reaction rates.

Introduction

It is well known that, in addition to the hydrogen pp chain, in stars more massive than the Sun, hydrogen can burn in the reactions of the carbon-nitrogen cycle (CNO cycle) [1]. The sequence of the cold CNO cycle consists of the following reactions: $^{12}C(p,\gamma)^{13}N(\rightarrow^{13}C+ e^{+} +\nu_e)$ $^{13}C(p,\gamma)^{14}N(p,\gamma)^{15}O(\rightarrow^{15}N+ e^{+} +\nu_e)$ $^{15}N(p,\alpha)^{12}C$. In this sequence, four protons are transformed into α particle (4 p → α) and as a result the energy of 26.73 MeV is released. Approximately 1.7 MeV of this energy is carried away by the neutrinos. As calculations show, the rate of energy release in the CNO cycle with increasing temperature ($T \sim 10^7$ K) increases much faster than the rate of energy release in the *pp*-chain.

The ^{12}C(p,γ)^{13}N reaction is the first reaction of the hydrogen-burning CNO cycle and plays an important role as a source of generation of both nuclear energy [1] and low-energy neutrinos [2-5] in massive stars. In the low-energy region, the ^{12}C(p,γ)^{13}N radiative capture reaction with formation of ^{13}N nucleus in the ground state mainly goes via both direct and resonant ($E^* = 2.365$ MeV, $J^\pi = 1/2^+$ and $E^* = 3.502$ MeV, $J^\pi = 3/2^-$) captures. Therefore, calculations of the ^{12}C(p,γ)^{13}N reaction astrophysical S-factor, which is based on the analysis of experimental data, should take into account the contributions of the abovementioned two resonant and direct radiative captures, as well as their interference, in the energy region $E_{c.m.}$ < 2.5 MeV (c.m. here is the center of mass frame). Unfortunately, in the energy region between these two resonances, the available experimental data have large uncertainties [1].

Therefore, in this region $E_{p,\ lab.}$ = 1100- 1400 keV (lab. here is the laboratory frame), we have made new experimental measurements of the astrophysical S-factor for the $^{12}C(p,\gamma)^{13}N$ radiative capture reaction with an uncertainty of about 16%. The calculation of the astrophysical S-factor, including the analysis of our new experimental data, has been made within the modified R-matrix method proposed previously in [6-9].

Experimental method and results of the measurements

The experimental part of our work was done on the electrostatic tandem accelerator UKP-2-1 of the Institute of Nuclear Physics ME RK in Almaty [10]. Protons were accelerated to energies $E_{p,\ lab.}$ = 340-1400 keV. Calibration of proton energies in the beam was made with uncertainties of ± 1 keV according to the $^{19}F(p,\alpha\gamma)^{16}O$ and $^{27}Al(p,\gamma)^{28}Si$ reactions with many well-separated resonances in the region of $E_{p,\ lab.}$ = 340-1400 keV [11, 12].

In our experiments, a specially made reaction chamber [6] with indium vacuum seals, a water-cooled target holder, and a quartz glass for obtaining a luminous image of the beam shape in front of the target were used. By an external handle, the quartz glass could be placed in front of the target for alignment. The γ-ray registration system was realized by using high-pure Germanium (HPGe) γ-detector with a Ge-crystal of volume of 111 cm^3. To reduce the room and cosmic ray background the γ-detector was surrounded by 6 cm thick lead shield. The resolution of the γ-detector was about 5 keV at E_γ = 2200 - 3250 keV. The target was produced by sputtering natural carbon onto a 2 mm thick Cu substrate (thickness ≈ 2 mm, length ≈ 30 mm, and width ≈ 15 mm). The thickness of the carbon film sputtered onto the substrate was 110 ± 8.8 $\mu g/cm^2$. The detailed description of the reaction chamber, the target production technology, and the target thickness determination method can be found in Refs. [6, 13, 14].

The absolute detector γ-ray efficiency for E_γ = 2200 - 3250 keV was determined by using γ-lines (E_γ = 2034.92, 2598.58 and 3253.6 keV) of a calibrated ^{56}Co source, with γ-lines intensities known to better than 4.5% [15].

When measuring the absolute efficiency, the detector and the ^{56}Co source were located precisely in the geometry of the experiment. At the same time, the statistical uncertainty in determining the number of counts for each γ-line was no more than 2%, and the electronics dead time did not exceed 1%.

The experimental differential cross sections of radiative capture were obtained at the measurement complex of INP [6], which allow to study the yields of the nuclear reactions on the extracted beams of the cyclotrons of the institute at the low and ultra low energies for the astrophysical and thermonuclear applications, see papers [6, 13, 14, 16].

During the measurements, γ-detector was about 8 cm away from the beam spot on the target. The γ-detector and ^{56}Co source were located with an uncertainty of about 1 mm. The dependence of the γ-ray registration rate on the source-detector distance was determined using ^{56}Co source. It was determined that at a distance of 8 cm, a deviation of ± 1 mm leads to a change in the γ-ray registration rate by ± 3%. Thus, uncertainties in the source and detector positions, dead time, γ-lines intensities, and counting statistics lead to an overall uncertainty of 6% for the detector efficiency over the entire energy interval of registered γ-rays (i.e. from 2200 to 3250 keV).

The differential cross sections of the $^{12}C(p,\gamma)^{13}N$ reaction for the transition to the ground state were determined at $E_{p,\ lab.}$ = 1100, 1150, 1250 and 1400 keV and at $\theta_{\gamma,\ lab.} = 0^0$.

Beam currents ranged from 5 to 8 μA. The energy spread of the beam was determined by the width of the front of the $^{27}Al(p,\ \gamma)^{28}Si$ reaction yield curve near the resonance at $E_{p,\ lab.}$ = 992 keV (resonance width < 0.1 keV) and did not exceed 1.5 keV. The accumulated charges on the target with an uncertainty of 3% were 0.28, 1.26, 1.51 and 1.4 Coulomb for $E_{p,\ lab.}$ = 1100, 1150, 1250 and 1400 keV, respectively. Dead-time effects were kept below 1.5% at all beam energies.

Figure 1 shows the γ-ray spectrum obtained at $E_{p,\ lab.}$ = 1100 keV and $\theta_{\gamma,lab.} = 0^0$. The energy calibration of the spectrometer was determined using well-known γ-lines of the ^{56}Co source and the room background γ-lines at 1461 keV (^{40}K) and at 2614 keV (Th).

The number of counts in the spectral peak with preliminarily subtracted background (trapezium shaped) divided by the calibrated integrator counter value was taken as the yield of the $^{12}C(p,\gamma)^{13}N$ capture reaction. Statistical uncertainties in the determination of the yields (including uncertainties introduced by backgrounds subtracted) were about 15% for the measurement at $E_{p,\ lab.}$ = 1100 keV and about 6% for the measurements at all other energies.

During each measurement, we computed the number of registered γ -rays of the transition to the ground state in ^{13}N (N_γ) over the integrator counter (N_p) as the yield per proton. For each of the energies presented in the work, the dependence of N_γ on N_p represented a straight line within the current statistical uncertainty of determining N_γ, which indicated the stability of the target and the stability of the beam position on it during the whole exposure.

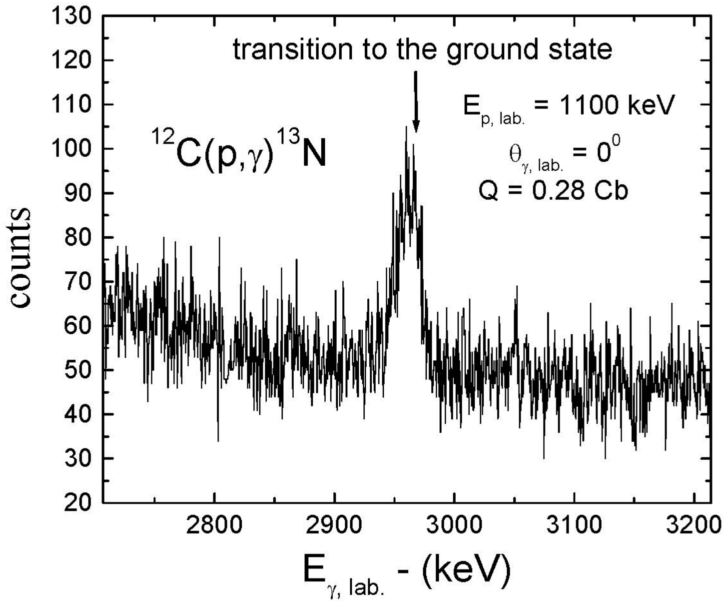

Figure 1 - γ-ray spectrum of the ^{12}C(p,γ)^{13}N reaction for the radiative capture transition to the ground state in ^{13}N as obtained at the laboratory proton energy of 1100 keV ($\theta_{\gamma,\ lab.} = 0^0$) by our HPGe γ-detector of volume 111 cm^3, located 8 cm. from the reaction region

Since, in the region $E_{p,\ lab.}$ = 1000-1400 keV the differential cross sections change only slightly with energy, as can be seen, for example, from previous works [6, 17], the effective laboratory energies were found using the expression $E_{p,\ eff} = E_{p,\ lab} - 0.5\Delta_{lab}(E_{p,\ lab})$, where Δ_{lab} is the energy loss of protons in the target.

Because the γ-detector energy resolution and the proton beam energy spread are significantly less than the energy losses of protons in the target, the upper part of the ^{12}C(p,γ)^{13}N reaction γ-line, for example, shown in Figure 1, repeats the course of the ^{12}C(p,γ)^{13}N reaction yield curve in the corresponding energy region (the spectrum in Figure 1 has too big statistical uncertainties), and the width of this γ-line is largely due to the target thickness. This circumstance allowed us to determine the target thickness also by analyzing the ^{12}C(p,γ)^{13}N reaction γ-lines shapes (i.e. as a second independent method) and to confirm the value obtained by the first method within the uncertainties. Moreover, the second method allowed us to check the uniformity of the target thickness for all the spectra obtained.

The differential cross sections of the ^{12}C(p,γ)^{13}N reaction for radiative capture to the ground state of ^{13}N at $\theta_{\gamma,\ lab} = 0^0$ were determined by using the relation

$$\frac{d\sigma}{d\Omega}(E_{p,\ eff.}, 0^0) = \frac{N_\gamma}{N_p\ N_{C^{12}}\ \varepsilon(E_{\gamma,\ eff.})}$$

where N_γ is the number of counts observed for the capture transition, $\varepsilon(E_{\gamma,\ eff.})$ is the absolute detector γ-ray efficiency, $E_{\gamma,\ eff.} = E_{p,\ lab.}\frac{12}{13} + 1941 - 0.5\,\Delta_{lab.}(E_{p,\ lab.})$, N_p is the number of incident protons, and $N_{C^{12}}$ is the areal density of ^{12}C atoms.

As an additional test of the method for obtaining the absolute values of the differential cross sections, we have measured the yields over the $^{12}C(p,\gamma)^{13}N$ resonance at $E_{p,\ lab.}$ = 457 keV (the differential cross sections in this energy range are known, for example, from [6, 17] with uncertainties of no more than 10%). Due to the energy losses of protons in the target in this energy region match with the resonance width (which is about 40 keV) the yields in the resonance region were determined by the relation

$$N_\gamma = N_p\ N_{C^{12}} \int_{E_{p,\ exit}}^{E_{p,\ lab.}} \frac{d\sigma}{d\Omega}(E, 0^0)\ \varepsilon(E)\ \frac{d\Delta}{dE}(E)\ dE$$

where $E_{p,\ lab.}$ is the proton energy at the target entrance ($E_{p,\ lab.}$ = 440, 450, 460, 470, 480 keV), $E_{p,\ exit}$ is the corresponding proton energy at the target exit, $\frac{d\sigma}{d\Omega}(E, 0^0)$ is the differential cross section of the $^{12}C(p,\gamma)^{13}N$ reaction for the capture to the ground state of ^{13}N at $\theta_{\gamma,\ lab.} = 0^0$ (the experimental data were taken from [6, 17]), $\frac{d\Delta}{dE}(E)$ is the stopping power of protons in carbon (calculated by the LISE++ program [18]). Such measurements were carried out before and after the main experiments, and the calculated and measured yields matched within the uncertainties.

The differential cross sections obtained in present work are given in the second row of Table 1. Assuming isotropy in the angular distributions of the $^{12}C(p,\gamma)^{13}N$ reaction in the energy region of incident protons from 400 to 1390 keV (which is confirmed with uncertainties of 10% in the works [6, 17]) in the present work, the total sections are calculated according to the formula:

$$\sigma(E_{p,\ eff.}) = 4\pi \frac{d\sigma}{d\Omega}(E_{p,\ eff.}, 0^0)$$

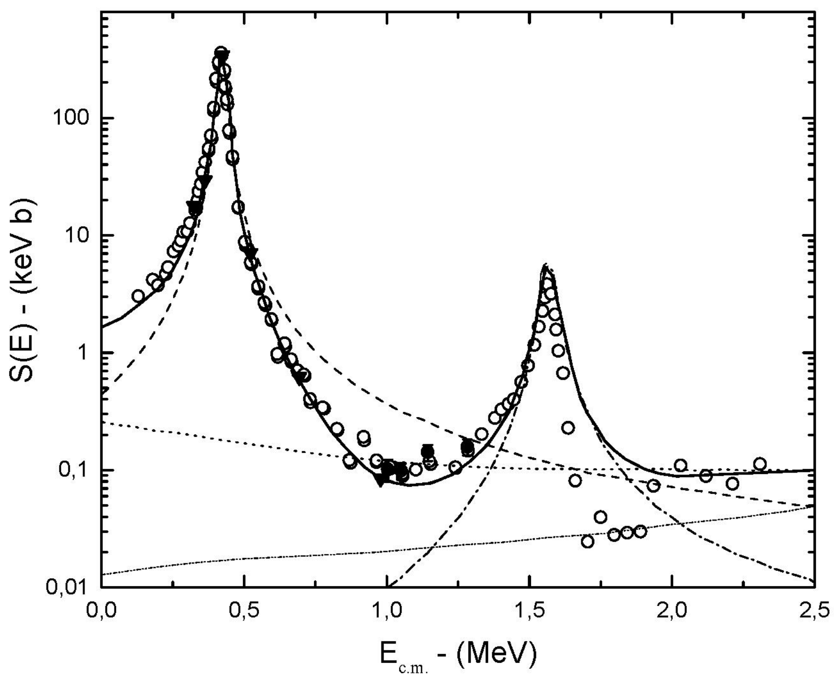

Figure 2 - The astrophysical S-factor for the $^{12}C(p,\gamma)^{13}N$ reaction. The experimental data: filled circles are the result of the present work, filled triangles are the data from [6] and open circles are the data from [17]. The solid line is our fit, dotted line is our calculated contribution for the direct radiative capture, dashed (dashed-dotted) line shows our calculated contribution for the first (second) resonance and dashed-dotted-dotted line presents our calculated contribution for the third (E^* = 10.250 MeV, $J^\pi = 1/2^+$) γ-resonance tail

Further, according to the relation:

$$S(keV\ b) = \sigma(b)\ E(keV)\ \exp(\frac{180.29}{\sqrt{E(keV)}})$$

the astrophysical S-factors were calculated, which are given in the third row of Table 1 and are shown in Figure 2 in comparison with the results of previous works. From Figure 2, it is clear that the experimental data of our work are in good agreement with the results obtained in [6, 17].

Table 1 + Experimental differential cross sections and experimental astrophysical S - factors of the $^{12}C(p,\gamma)^{13}N$ reaction for radiative capture to the ground state of ^{13}N

$E_{p,\ eff.}$ (keV)	1088	1138.5	1239.3	1390
$\frac{d\sigma}{d\Omega}^{exp.}(E,0^0)$ – ($\frac{\mu b}{sr}$)	0.027±0.0049	0.029±0.0035	0.048±0.0058	0.064±0.0077
$S^{exp.}(E)$ – (MeV b)	0.1±0.02	0.098±0.015	0.14±0.022	0.16±0.025

Results of the $^{12}C(p,\gamma)^{13}N$ reaction astrophysical S-factor calculation by the modified R-matrix analysis method

The detailed description of the modified R-matrix method that was used in the calculations can be found in [6-9, 19, 20]. The input parameters required for calculating the $^{12}C(p,\gamma)^{13}N$ reaction astrophysical S-factor for transition to the ground state of ^{13}N (channel radius, proton width and radiative widths of the first and second resonance states) were taken from [6]. The experimental results of this work and the experimental results of [6, 17] were used as experimental data. The asymptotic normalization coefficient (ANC) value was taken equal to 1.43 ± 0.09 $fm^{-1/2}$ [21, 22] as in [6].

The results of our calculations of the $^{12}C(p,\gamma)^{13}N$ reaction astrophysical S-factor taking into account the analysis of new experimental data completely repeat our earlier results [6] and are shown in Figure 2, where the contributions of direct radiative capture (dotted line), first resonance (dashed line) and second resonance (dashed-dotted line) are given separately. The inclusion of the third resonant state (E^* = 10.250 MeV, $J^\pi = 1/2^+$, the proton width Γ_3^p = 280 keV [23] and the radiation width Γ_3^γ = 6000 eV [6]) tail part contribution in the calculations significantly improved the theoretical description of the experimental data (dashed-dotted-dotted line). The values of the resonant parameters used in present work are listed in Table 2 of [6].

The results of our calculations of the $^{12}C(p,\gamma)^{13}N$ reaction astrophysical S-factors for the transition to the ground state of ^{13}N at the most important energies for astrophysics E = 0; 25 and 50 keV are S(0 keV) = 1.62 ± 0.20 keVb, S(25 keV) = 1.75 ± 0.22 keVb and S(50 keV) = 1.88 ± 0.24 keVb, respectively. The uncertainties quoted for these astrophysical S-factors are due to those of the parameters of proton and γ widths and ANC given earlier [6]. Our central value for S(25 keV) within the specified uncertainty is consistent with the values of S(25 keV) = 1.54 ± 0.08 keVb obtained in [24] and S(25 keV) = 1.45 ± 0.20 keVb obtained in [17], and in satisfactory agreement with the value of S(25 keV) = 1.33 ± 0.15 keVb obtained in [25, 26]. However, our result for S(0 keV) is noticeably larger than that of S(0 keV) = 1.0 and 1.3 keVb obtained in [27] using the Minnesota and V2 forms of the NN potential, respectively, as well as the value of S(0 keV) = 1.4 keVb recommended in [28]. It should be emphasized that a value of S(25 keV) = 1.54 ± 0.08 keVb in [24] has been also obtained within the R-matrix approach [7, 9]. In contrast to our work in [24], the ANC, which is responsible for the contribution of direct radiative capture, was a fitting parameter in order to better describe the experimental data at first resonance region. As a result, this artificial overestimation of the ANC value led to resonance (Γ_1^γ = 0.50 ± 0.05 eV) decrease in the total amplitude of the radiative capture process, which led to an underestimated value of S(25 keV). In our present work, we used the fixed ANC value obtained independently from the analysis of the peripheral proton transfer reaction [21, 22], which allowed us earlier in [6] to carry out fitting of resonant width parameters (for example, Γ_1^γ = 0.65 ± 0.07 eV) in a correct way.

$^{12}C(p,\gamma)^{13}N$ reaction rate

The calculated astrophysical S-factors, as well as the data of [6, 17], were used for calculating the rate of ^{13}N nucleus formation in the stellar interior as a function of stellar temperature T_9, where $T_9 = T \times 10^9$ K. The Maxwellian-averaged reaction rates $N_A(\sigma v)$ as a function of temperature are defined by

$$N_A(\sigma \upsilon) = N_A \left(\frac{8}{\pi \mu} \right)^{1/2} (k_B T)^{-3/2} \int_0^\infty \sigma(E) \exp(-E / k_B T) E dE ,$$

where N_A is Avogadro's number, k_B is the Boltzmann constant, and $\vartheta = \sqrt{2E / \mu}$ is the relative velocity of the colliding particles. The calculation performed in the present work matches with the results we obtained in [6]. Figure 3(a) shows the reaction rates of our calculation (solid line) and its comparison with the experimental data of [29]. It is seen that the result of our calculation is in good agreement with those recommended in [29]. That work used a very different method, with independent systematic uncertainties, and cited uncertainties equal to the estimated values for unobserved energies. The ratio of our calculation of reaction rates $N_A(\sigma v)$ to the result recommended in [30] (solid line) is also given in Figure 3(b). As is seen from Figure 3(b) there is a noticeable difference (up to ≈ 20%) between our recommended results and those given in [30] within a wide interval of stellar temperatures. The probable reason for the observed difference is that in [30] the calculation of the reaction rates included all the experimental astrophysical S-factors obtained in [17, 25, 26, 30], some of which have uncertainties up to 40%, by a smooth spline fit. Moreover, it was assumed in [30] that the spectroscopic factor for the ground state of the ^{13}N nucleus in (^{12}C + p) - configuration is 1. However, as can be seen from [31], this assumption is not justified and, in fact, the empirical value of the spectroscopic factor is 0.55 ± 0.18. It can be considered that the result in [30] is model-dependent, while our calculation of the reaction rate does not contain free parameters and in this sense it can be regarded as more reliable.

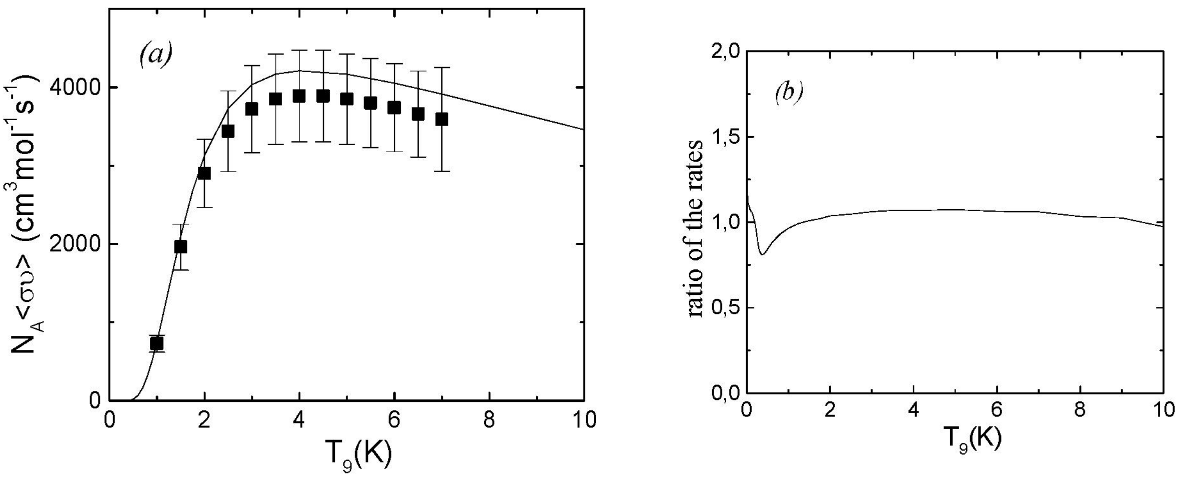

Figure 3 - (a) The $^{12}C(p,\gamma)^{13}N$ reaction rate calculated in present work (solid line) and points taken from [29].
(b) The ratio of the $^{12}C(p,\gamma)^{13}N$ reaction rates N_A (συ) of present work to those from [30] (solid line)

Conclusion

In this work new experimental data on the differential cross sections of the $^{12}C(p,\gamma)^{13}N$ reaction for the transition to the ground state of ^{13}N have been obtained at four energies from 1088 to 1390 keV in the laboratory system at an angle of 0^0 with uncertainties of about 12%. The astrophysical S-factors for radiative capture of a proton to the ground state of ^{13}N (the only bound state of this nucleus) have been determined with uncertainties of about 16% at these energies. Our experimental data are in good agreement with those previously obtained in [6, 17].

We have analyzed the new experimental data on $^{12}C(p,\gamma)^{13}N$ reaction astrophysical S-factors for the transition to the ground state of ^{13}N at extremely low energies within the one-level R-matrix approach where the direct part of the amplitude is expressed in terms of the ANC for ^{13}N in the (p + ^{12}C) channel. Such a parametrization allowed us to calculate the direct capture part of the amplitude in a correct way using the indirectly measured value of ANC found previously in [21, 22] from the analysis of the peripheral $^{12}C(^{3}He,d)^{13}N$ reaction.

It is shown that using information about ANC value provides good fitting of the experimental astrophysical S-factor of the $^{12}C(p,\gamma)^{13}N$ reaction for the transition to the ground state of ^{13}N and reduces to a minimum the model dependence of the calculated direct capture part of the astrophysical S-factor on the parameters of the R-matrix approach . In general, the results of the new analysis of the experimental astrophysical S-factors match with the results of our previous work [6].

We have also calculated the rates of the $^{12}C(p,\gamma)^{13}N$ reaction for the astrophysically important transition to the ground state of ^{13}N in the low energy region. It has been shown that these present reaction rates (as well as the rates of [6]) are in good agreement with those recommended in [29] using a very different technique from that described in present work, whereas a notable difference (up to ≈ 20%) occurs between our result (as well as the result of [6]) and that given in [30] within a wide interval of stellar temperatures.

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ТӨМЕН ЭНЕРГИЯЛАРДАҒЫ Р-^{12}С РАДИАЦИЯЛЫҚ ҚАРПУЫНЫҢ ЖАҢА НӘТИЖЕЛЕРІ

Аннотация. Жұмыста үдетілінген протондардың 1088 – 1390 кэВ энергияларында 0^0 бұрышта $^{12}C(p,\gamma)^{13}N$ радиациялық қарпуы реакциясының ^{13}N ядросының негізгі күйіне көшуінің дифференциалдық қимасының жаңа өлшеулер нәтижелері (12% дәлдікпен) ұсынылды. Алынған дифференциалдық қималар және осы энергия аймағындағы бұрыштық таралулардың изотроптық қасиетке ие болатындығына негізделе отырып, 16 % дәлдікпен $^{12}C(p,\gamma)^{13}N$ реакциясы үшін ^{13}N негізгі күйге ауысуының астрофизикалық S факторы анықталды. Қателер шегінде, осы жұмыстың эксперименттік нәтижелері бұрынғы жұмыстардың деректерімен сәйкес келеді. Модификацияланған R - матрицалық әдісті пайдалана отырып, астрофизикалық S-фактор бойынша эксперименттік мәліметтер талданды. Аса төменгі энергияларда ^{12}C ядросымен протондардың тікелей қарпылуына байланысты есептеу қәтеліктерін азайту мақсатында талдау барысында ^{12}C және ^{13}N ядроларының байланысқан күйлерінің толқындық функцияларының қабаттасу интегралының өлшенілген асимптотикалық нормалау коэффициентінің мәні пайдаланылды. Массалар орталығы жүйесінде E = 0,25 және 50 кэВ энергияларда $^{12}C(p,\gamma)^{13}N$ реакциясынан ^{13}N ядросының негізгі күйге ауысуы үшін S-фактордың есептік мәндері келтірілген. 0 - 10^{10} К температура аймағында $^{12}C(p,\gamma)^{13}N$ термоядролық реакциясының жылдамдықтары анықталды. Бұл жұмыстың есептеу нәтижелері бұрынғы жұмыстардың эксперименттік және есептік мәліметтерімен салыстырылды.

Түйін сөздер: дифференциалдық қималар, толық қима, астрофизикалық S-фактор, асимптотикалық нормалау коэффициенті, реакцияның жылдамдықтары.

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НОВЫЕ РЕЗУЛЬТАТЫ ДЛЯ РАДИАЦИОННОГО ЗАХВАТА p-^{12}C ПРИ НИЗКИХ ЭНЕРГИЯХ

Аннотация. Представлены результаты новых измерений дифференциальных сечений реакции $^{12}C(p,\gamma)^{13}N$ радиационного захвата на основное состояние ^{13}N для угла 0^0 и при энергиях налетающих протонов от 1088 до 1390 кэВ (точность около 12%). На основе полученных дифференциальных сечений и в предположении об изотропном характере угловых распределений в данной области энергий с точностью около 16% определены астрофизические S – факторы реакции $^{12}C(p,\gamma)^{13}N$ для перехода на основное состояние ^{13}N. В пределах погрешностей экспериментальные результаты настоящей работы согласуются с данными более ранних работ. С использованием модифицированного R – матричного метода проведен анализ экспериментальных данных по астрофизическому S – фактору. В целях минимизации вычислительной неопределенности, связанной с прямым захватом протона ядром ^{12}C для самых низких энергий, при анализе использовалось значение измеренного раннее асимптотического нормировочного коэффициента интеграла перекрытия волновых функций связанных состояний ядер ^{12}C и ^{13}N. Для энергий E = 0,25 и 50 кэВ в системе центра масс приведены вычисленные значения S – фактора реакции $^{12}C(p,\gamma)^{13}N$ для перехода на основное состояние ^{13}N. В области температур от 0 до 10^{10} К получены скорости термоядерной реакции $^{12}C(p,\gamma)^{13}N$. Результаты расчетов настоящей работы сравниваются с экспериментальными и расчетными данными предыдущих работ.

Ключевые слова: дифференциальные сечения, полные сечения, астрофизический S-фактор, асимптотический нормировочный коэффициент, скорости реакции.

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