

DIFFERENTIAL CROSS SECTION MEASUREMENT OF RADIATIVE CAPTURE OF PROTONS BY NUCLEI ^{13}C

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INTRODUCTION

The reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$ is the important one for the astrophysics, not only for nuclear synthesis of CNO elements, but also for nuclear synthesis of elements participating in subsequent combustion of helium [1]. The predominant yield of the reaction occurs at protons energies of less than 1 MeV. However, the clearness of the capture mechanism in this energy region is made difficult because of the superposition of the contribution of the low - energy part of the resonance 1320 keV onto the cross section. Last experimental data for a wider energy region, informed in the work [1], and results of previous works, mentioned in that work, give reason for further continuation of the study of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$. Measured data of the work [1] in the region of $E_p = (320 \div 900)$ keV at the angles of 0^0 and 90^0 are obviously insufficient.

In the present work measurements of differential cross sections of the reaction were carried out at protons energies $E_p = 991 \div 365$ keV, the accuracy is not worse than 10%. There was

studied the most (from the astrophysical point of view) important process of protons capture by ^{13}C nuclei onto the ground state of the ^{14}N nucleus.

The theoretical investigation of the given reaction included calculation of cross sections. The cross sections were calculated within the framework of model of direct capture with the using of optical potentials for the description of a channel of scattering. The wave functions of a bound state were generated in a potential reproducing binding energy of a proton in ^{14}N nucleus. Results of calculations were compared with the experimental data.

EXPERIMENT

Proton beams of $10\ \mu\text{A}$ were provided by the 2 MV "RAC-2-1" accelerator at the Institute of Nuclear Physics of Almaty.

The differential cross sections of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$ at the proton energy $E_p = 991, 558$ and $365\ \text{keV}$ were measured there. The distance from the detector to the target was equal to 4cm . The beam current on the target was $10\ \mu\text{A}$. The target was placed in the high-vacuum chamber (Fig. 1). Details concerning arrangement and the conducting of experiment are described in [2].

In Fig. 2 there is shown the gamma-rays spectrum from the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$, measured at the proton energy $E_p = 365\ \text{keV}$.

The ^{13}C (99%) targets, used in the experiment, were sprayed onto copper base. The target thickness was determined by incident protons energy losses in the target. The energy losses were clearly reflected in the corresponding spreading of transitions of radiation capture, as it is shown in Figs. 3 a) and 3 b). The statement about the gamma-lines spreading is valid in this case, because energy losses in the target are here significantly higher, than the energy resolution of the detector. The peak width of the radiation capture gamma-line at half-height corresponds to energy losses of incident protons in the target. From the Table of brake values for protons in carbon [3] there was determined that the thickness of the target was $140 \pm 5\% \mu\text{g}/\text{cm}^2$. The upper part of gamma-lines in Figs. 3 a) and 3 b) repeats the course of excitation function curve of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$ in this energy region.

At every energy there was measured the angular distribution of cross sections of the reaction at the angles of $\theta_\gamma = 0^\circ, 90^\circ$ and 135° . The correction for protons effective energy, during the measurements of excitation function at the expense of energy losses of protons in the target, was carried out by the formula $E_{\text{eff}} = E_p - 0,5 \Delta_{\text{lab}}(E_p)$.

In Fig. 4 there are shown results of measurements of angular distributions, differential cross sections of radiation capture of protons by ^{13}C nuclei onto the ground state of the ^{14}N nucleus calculated from the present measurements.

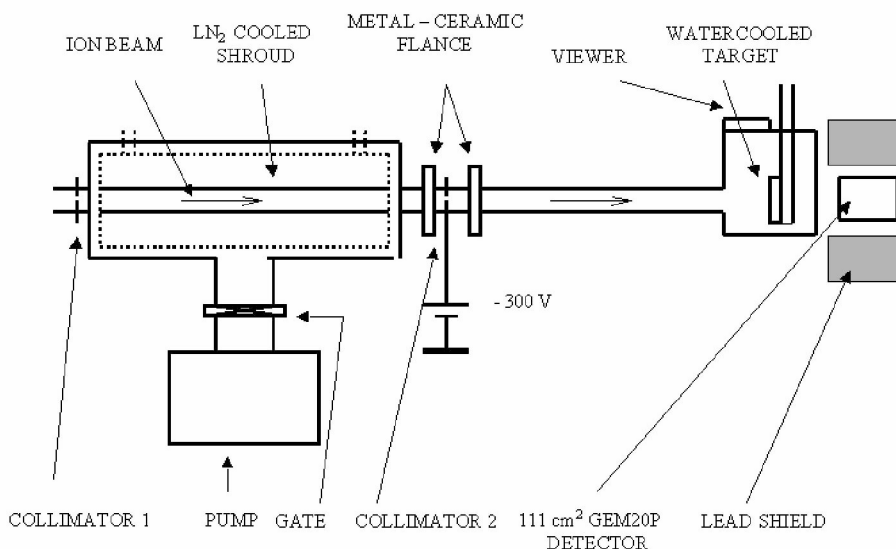


Fig. 1. The diagram of the high – vacuum chamber of reactions.

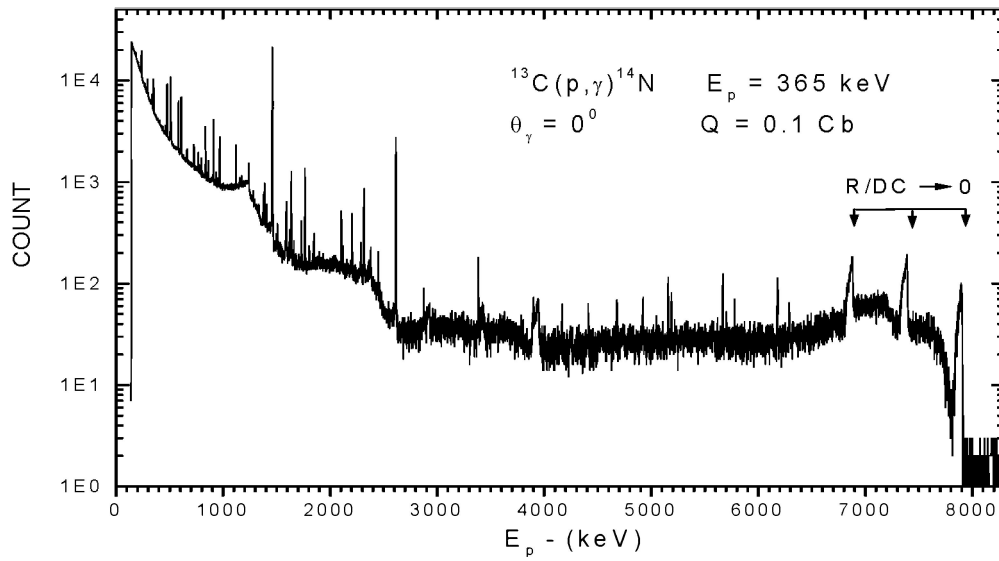


Fig. 2. The example of the gamma - spectrum of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$, obtained by the GEM20P detector of the volume of 111 cm^3 , placed at the distance 4cm from the reaction region.

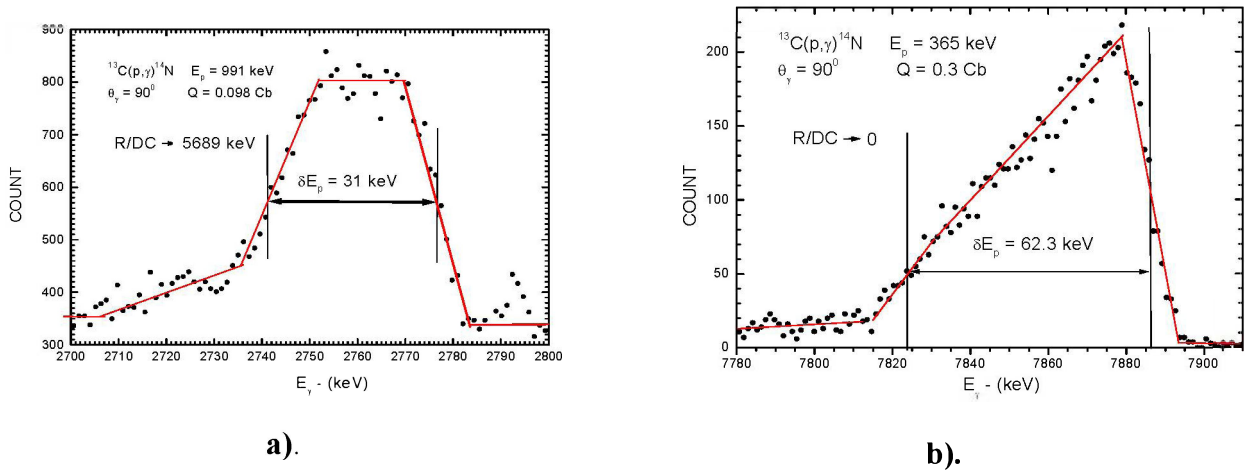


Fig. 3. The line spreading of gamma-transition of the radiation capture of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$ at the expense of the target thickness.

a) ($R/DC \rightarrow 5689\text{ keV}$) $\delta E_\gamma = 31\text{ keV}$, at $E_p = 991\text{ keV}$, corresponds to the thickness of $(140 \pm 8)\text{ }\mu\text{g/cm}^2$.

b) ($R/DC \rightarrow 0\text{ keV}$) $\delta E_\gamma = 62\text{ keV}$, at $E_p = 365\text{ keV}$, corresponds to the thickness of $(140 \pm 8)\text{ }\mu\text{g/cm}^2$.

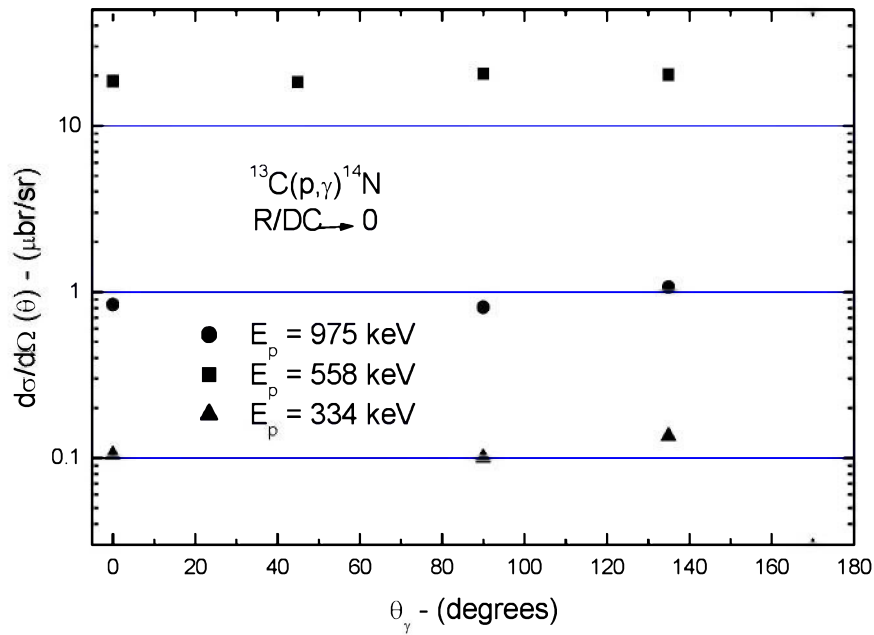


Fig. 4. Angular distributions of differential cross-sections of radiation capture of protons by ^{13}C nuclei onto the ground state of the ^{14}N nucleus.

ANALYSIS OF EXPERIMENTAL DATA

The analysis of experimental data on elastic scattering of protons on ^{13}C - nuclei was carried out in the protons energy range of $E_p = 7 \div 200$ MeV.

With the use of above-chosen geometrical “OP”-parameters there were carried out optical-model calculations of protons elastic scattering on nuclei ^{13}C in wide energy range and there was determined the energy dependence of the depth of the real part of the optical potential “ V_R ”.

For protons elastic scattering on the ^{13}C -nucleus the construction energy dependences of the “ V_R ” have the linear character:

$$V_R = (52.93 - 0.26 \cdot E_p), \text{ in the energies range of from 7 MeV to 71.8 MeV;}$$

$$V_R = (51.09 - 0.21 \cdot E_p), \text{ in the energies range of from 7 MeV to 200 MeV.}$$

There were calculated differential and integral cross-section of the $^{13}\text{C}(p,\gamma)^{14}\text{N}$ reactions with the use of phenomenological potentials. The spectroscopical factor for the separation of proton from the ^{14}N -nucleus was taken from the work [4]. In Fig. 5 there are shown total cross sections of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$. Obtained values of cross-sections are by 50% less than experimental data of the work [1]. This difference may be connected with the fact that the proton binding energy in the ^{14}N -nucleus is large enough ($E = 7.6$ MeV), analogously with the case of the ^{11}B -p system, and besides, in all probability, the capture takes place microscopically on neutron of the ^{13}C -nucleus $^{13}\text{C} \rightarrow ^{12}\text{C} + n$, which has the high centrifugal barrier and is surrounded by the Coulomb barrier of the ^{12}C – nucleus. The consideration of these effects was not in the present work. This difference may be eliminated with the help of the introduction of orbitally-depending potentials.

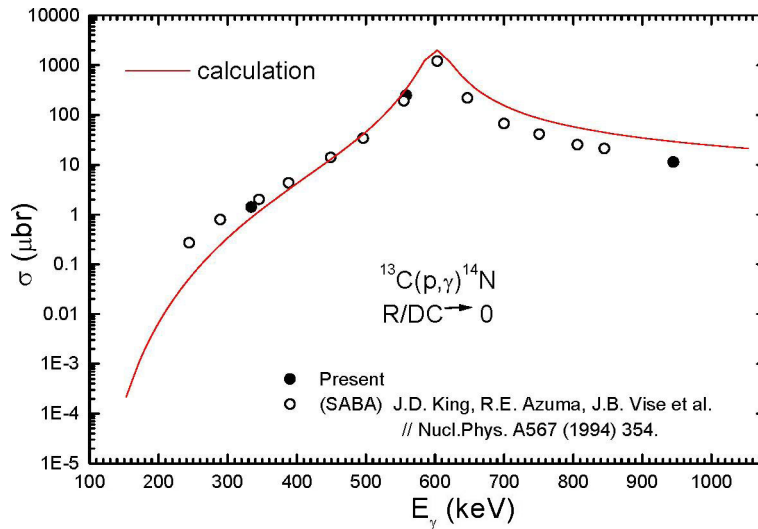


Fig. 5. Results on total cross-sections of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$, calculated from our measurements (black points) in comparison with data of the work (J.D. King, R.E. Azuma, J.B. Vise et al. // Nucl.Phys. A567 (1994) 354. (SABA)) (light points).

CONCLUSIONS

There were carried out measurements of differential cross sections of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$ of the direct capture ($R/DC \rightarrow 0$) at the proton energies $E_p = 991, 558$ and 365 keV, respectively. At every energy there were measured angular distributions of the reaction at the angles $0^\circ, 90^\circ$ and 135° . The measurements at the angles of $0^\circ, 90^\circ$ and 135° were carried out for the first time. From the measurements of differential cross sections there were calculated total cross sections of the reaction $^{13}\text{C}(p,\gamma)^{14}\text{N}$. There was obtained a good agreement with results of the work [1].

REFERENCES

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