^{7}Be GENERATION IN THE REACTION OF TWO-PARTICLE PHOTODISINTEGRATION OF ^{14}N NUCLEUS

M. S. Glaznev, E. S. Gorbenko, A. L. Bespalov, R. T. Murtazin*, A. F. Khodyachikh

National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov, Ukraine

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The reaction of two-particles nitrogen nucleus photodisintegration with ^{7}Li and ^{7}Be in the final state are investigated using diffusion chamber, which is placed into the magnetic field and filled with 15% nitrogen and helium compound. Chamber was irradiated with gamma rays from electron accelerator. The method of extraction of the reaction from the background two-particle reactions with multi-charged ions in the final state was created. Differential, full and integral cross-section of the reaction were measured. The results were compared with experimental data, where the full isotope ^{7}Be output at ^{14}N photodisintegration reaction was measured.

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1. INTRODUCTION

Photodisintegration reactions of light nuclei are interesting in nuclear physics. At low energies they give information about few-nucleon systems behavior and upper states of nuclei in the giant resonance area [1]. Photonuclear reactions are caused by the well known electromagnetic interactions. That's why their investigation gives important information about fundamental properties of nuclear forces, such as nucleon-nucleon interactions and exchange meson currents for nuclear physics [2].

Investigation of lithium and beryllium isotopes interaction at low energies is important for understanding of certain astrophysics and inner stars structure problems [3]. But experimental investigation of their interactions at low energies is difficult. That's why reverse reactions, such as photodisintegration of nuclei with listed isotopes generation, are useful for understanding of existent processes. Photonuclear reactions are important factor in nuclear fusion and astrophysical processes [3, 4].

The monitoring of radionuclide content in near-ground atmospheric shell is an important part of information about nuclear reactions. ^{7}Be short-lived isotope gives significant contribution in air radioactivity. It is considered that in the atmosphere ^{7}Be generates in reactions of cosmogenic and solar proton and neutron interaction with nitrogen and oxygen nuclei[5]. But it is shown in paper [6], that photonuclear reactions, which were not considered until now mainly because of a lack of experimental data in the literature, can give significant contribution into ^{7}Be isotope generation. ^{7}Be nucleus is interesting not only from the perspective of its radioactive influence on the biological systems, but as an indicator of a pollutants accumulation by environment.

In this paper the results of research findings of photodisintegration reaction of ^{14}N nucleus with ^{7}Li and ^{7}Be in the final state are shown.

2. EXPERIMENTAL METHOD

Experiment was held on a diffusion chamber, placed in the $15\,kOe$ magnetic field, exposed with bremsstrahlung from Kharkov $300\,MeV$ electron linear accelerator with $150\,MeV$ peak energy. The chamber filled with 15% nitrogen with helium mixture at pressure of 2 at. Nitrogen nucleus photodisintegration event was separated visually with ease. Low pressure in the chamber and target and detector matching made possible to investigate reactions of nitrogen photodisintegration basically from reaction threshold. The reactions with two particles in the final state were selected for studying. The conclusion about particle stopping in the working space of the chamber and about that fact if its mass is heavier than deuteron mass was made by track density changing. The reactions of two-particle photodisintegration of nucleus listed below are matching these criteria:

$$\gamma + {}^{14}N \to {}^{7}Li + {}^{7}Be\,, \tag{1}$$

$$\gamma + {}^{14}N \to {}^{4}He + {}^{10}B\,, \tag{2}$$

$$\gamma + {}^{14}N \to {}^{3}He + {}^{11}B\,, \tag{3}$$

$$\gamma + {}^{14}N \to {}^{3}H + {}^{11}C\,. \tag{4}$$

Only in the fourth reaction tritium ran out the working space of the chamber, all products of the other reactions stopped in the chamber.

*Corresponding author E-mail address: rumurtazin@gmail.com

The reaction was considered as two-particle one if the ions and γ-quantum momentums were situated in the same plane. An angle of the tracks coincidence with the plane was measured with $10°$ accuracy for every event. An event was rejected if this angle was above $15°$. Since light ions have different energies, then it is impossible to identify them by ionization. Width and density of the heavy ions tracks almost didn't distinguish from those parameters of the light ions. Calculations show that in the reactions 2...4 a light ion with any γ-quantum energy and outlet angle has longer track. In the first reaction the path of the ^7Li ion is shorter then the pass of the ^7Be ion at γ-quantum energy less than $2\,MeV$ above reaction threshold and at outlet angle greater than $90°$. The main criteria for reaction identification were track length data, scaled to the standard conditions. During scaling it is also changes of density of the mixed gases because of temperature changes with increasing the distance between track and median plane counted. An obtained value was called track path length.

Because of different charges and masses of ions, it would be excepted a difference in track path lengths ratio η in the reactions. With assumption that all events refer to the first reaction there was distribution of η calculated. For this purpose the kinetic energy and the absolute value of momentum of the first ion was defined from its path using path-to-energy relation tables. The momentum direction in space was defined from the track coordinates. Since the reaction is two-particle one, then the γ-quantum energy and the kinematical parameters of the second ion was calculated using the parameters of the first one. From the kinetic energy of the second ion it is possible to get its path and calculate the value of η

On Fig.1 events distribution from η is shown with filled circles. Thus if η is lower 2.5, then an event concerns to the first reaction. Comparing experimentally measured η and calculated one it is possible to determine the first reaction.

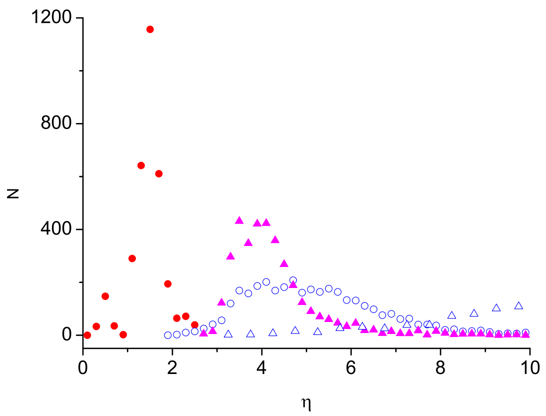

Fig.1. *Number of events distribution versus η*

The filled triangles show the second reaction events distribution. The distribution begins at η value greater then 2.5 and continues till 7.0. The distribution for the third reaction is shown empty circles. It begins at η greater 2.5 and lasts till 8.0. The events of the second and the third reactions are situated in this interval. Comparing experimentally measured η and calculated one it is possible to determine these reactions. The curve with empty triangles shows the fourth reaction distribution. ^3H ion is single-charged therefore it has much longer path then ^3He ion with the same energy. Therefore the curve starts at $\eta = 6$ and lasts till $\eta = 30$.

An event considered identificated, if the measured ratio matched with calculated one within the limits of errors. But because of measurement errors of path lengths of heavy ions, the ratio comparison not always gave an opportunity to identificate the reaction. That's why the other data were used. The length of the short measured track with its calculated value was compared. It is possible to determine γ-quantum energy from the parameters of each ion. For each one of the four reactions the difference $\delta E = E_1 - E_2$ was calculated, where E_1 is a γ-quantum energy, determined from the longer track, and E_2 is from the short one. The lowest value of δE determined the reaction, if the previous two criteria didn't allow doing this.

Diffusion chamber was placed in the magnetic field. Momentum, which is defined from track's curvature, is an average of its length. Its comparison with an average momentum determined by path, helps to identificate reaction if the track path length is enough. Because of ion recharge with medium, the ion charge is decreasing. According to tables [7] the proton and ion path length ratio at equal kinetic energy is greater on one nucleon then $5\,MeV$ equal to A/z^2, where A – atomic number of the ion, z – its charge. Ion path increasing comparing to A/z^2 multiplied proton path at low energies of ion can be explained by ion charge decreasing. Paths ratio allowed determining coefficients of charge decreasing for all ions. They don't have much changes with energy and on average is equal to 0.85 and 0.71 respectively for helium and lithium ions at energies to $2\,MeV$. The charge decreasing is considered in momentum determination by track curvature.

Path-energy relation [7] for light ions was examined by comparing with the experimental data and the data from literature. Energy of heavy ions was determined from light ions data. An energy dependence form path length changing was plotted. A satisfactory correlation of dependence with data was obtained [7] at energies up to $2\,MeV$.

An error of a track length measurement is $0.025\,cm$, of a noncomplanar angle $10°$, of a polar angle of the long tracks $1.0°$ and $2.0°$ for short tracks.

3. THE RESULTS OF THE EXPERIMENT

The γ-quantum energy was determined from kinematical parameters of the light ion, which were measured with the better accuracy due to longer track.

The events considered to the first reaction were distributed by the γ-quantum energy. The histograms with $1\,MeV$ step were plotted. All results are represented with points, placed in the middle of a step. Errors are statistical. In order to get full cross-section a calculated γ-quantum spectrum was taken. It has a shiff form. A soft component was removed by the beryllium filter with 2.5 radiation unit length.

Full cross-section dependence versus energy is shown on Fig.2. Near threshold the cross-section is increasing rapidly, then it is decreasing smoothly with energy. This reaction cross-section didn't measured earlier. In the energy interval from 28 to 39 MeV an integral cross-section $\sigma_{int} = (1.49 \pm 0.21)\,mbn{\cdot}MeV$

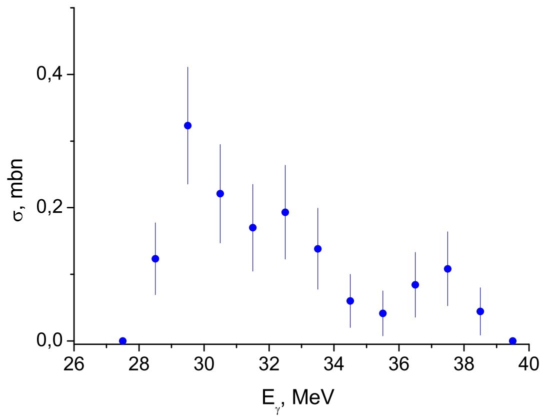

Fig.2. *Full cross-section dependence versus energy*

The differential cross-sections are plotted versus angle in the centre-of-mass system with 20° step in Fig.3, using events in all energy interval. The points are placed in the middle of a histogram. The errors are statistical.

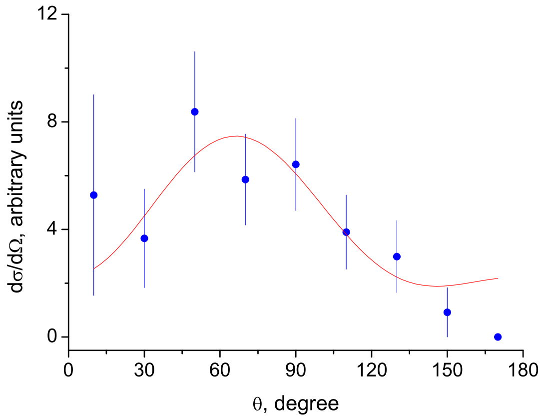

Fig.3. *The differential cross-section*

The angle cross-section dependence is not isotropic an it has a distinct asymmetry relative to 90°, which is caused by electrical quadrupole transition contribution. The total cross-section dependence with respect to the polar angle θ approximated with function:

$$d\sigma/d\Omega = a + b \cdot \sin^2\theta + c \cdot \sin^2\theta\cos\theta$$

As the result, the coefficients were obtained: $a = 2.2 \pm 1.1$, $b = 3.8 \pm 1.7$, $c = 5.9 \pm 2.4$.

4. THE RESULTS AND DISCUSSIONS

In paper [8] aluminum nitride targets, contained $0.3\,g/cm^2$ of nitrogen, were radiated with bremsstrahlung from electrons with energies 40, 50, 60, 70, 80 and 90 MeV. The converter was a tantalum bars with total thickness $4\,mm$. The exposure lasted for 12.5 hours with $1\,mkA$ current. The bremsstrahlung spectrum was calculated for every energy using electron transmission through the converter and the target modeling. The target activity, corresponded to unstable ^7Be nuclei disintegration from unknown reactions $^{14}N(\gamma, X)^7Be$ for all six electron energies, was measured.

Using the reaction $^{14}N(\gamma,^7Li)^7Be$ cross-section and the bremsstrahlung spectra for each electron energy, the number of ^7Be nuclei N_0 was obtained, which were generated in the target at the time of each exposition. The number of ^7Be nuclei, which are disintegrating per second $N = \lambda N_0 e^{-\lambda t}$, where $\lambda = ln2/T_0$, half-life period $T_0 = 53.3$ days. Since $t{\ll}T_0$, then $e^{-\lambda t}{\approx}1$, and the activity of the target $N = \lambda N_0$. At energy of the electrons 40 MeV the calculated activity is $2.4\,kBq$, which is 2.5 times as much as experimental value. Calculated activity versus electron energy dependence is shown with solid curve in Fig.4. The points shows the results of activity measurements in paper [8]. The curve is normalized on the first point. The increasing disagreement with energy testifies that $^{14}N(\gamma,^7Li)^7Be$ is not single photonuclear reaction on nitrogen, in which ^7Be nucleus is generation.

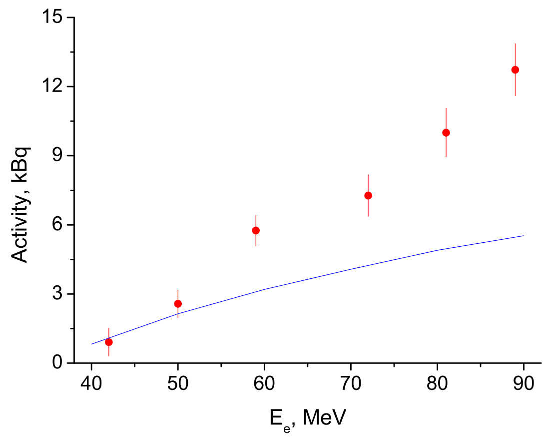

Fig.4. *^7Be activity*

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ОБРАЗОВАНИЕ ^7Be В РЕАКЦИИ ДВУХЧАСТИЧНОГО ФОТОРАСЩЕПЛЕНИЯ ЯДРА ^{14}N

М. С. Глазнев, Е. С. Горбенко, А. Л. Беспалов, Р. Т. Муртазин, А. Ф. Ходячих

Реакция двухчастичного фоторасщепления ядра азота с выходом изотопов ^7Li и ^7Be исследована с помощью диффузионной камеры, заполненной 15% смесью азота с гелием и помещенной в магнитное поле. Камера облучалась тормозными γ-квантами от линейного ускорителя. Разработан метод выделения реакции из фоновых двухчастичных реакций с многозарядными ионами в конечном состоянии. Измерены дифференциальные, полные и интегральное сечения реакции. Проведено сравнение результатов с данными эксперимента, в котором измерен полный выход изотопа ^7Be при фоторасщеплении ядра ^{14}N.

УТВОРЕННЯ ^7Be У РЕАКЦІЇ ДВОЧАСТКОВОГО ФОТОРОЗЩЕПЛЕННЯ ЯДРА ^{14}N

М. С. Глазнєв, Є. С. Горбенко, О. Л. Беспалов, Р. Т. Муртазін, О. Ф. Ходячих

Реакцію двочасткового фоторозщеплення азоту з виходом ізотопів ^7Li та ^7Be досліджено за допомогою дифузійної камери, яку заповнено 15% сумішшю азоту та гелію і розміщено у магнітному полі. Камера опромінювалася гальмівними γ-квантами від лінійного прискорювача. Розроблено метод виділення реакції з фонових двочасткових реакцій з багатозарядними іонами в кінцевому стані. Виміряно диференційні, повні та інтегральне перерізи реакції. Проведено порівняння результатів з даними експерименту, в якому виміряно повний вихід ізотопу ^7Be при фоторозщепленні ядра ^{14}N.