Physics

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1960

SovietRxiv

Abstract

Full Text

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PHOTODISINTEGRATION OF NUCLEI N^{14}

Several works have been devoted to the study of the photodisintegration of nitrogen nuclei ($^{1-4}$). However, a number of facts concerning the photodisintegration of N^{14} nuclei remained unexplored. It seemed of interest to us to clarify certain details of nitrogen photodisintegration, in particular the mechanism of the reaction (γnp), which has a large yield.

In the present work, the photodisintegration of nitrogen nuclei was studied with the aid of a Wilson chamber placed in a constant magnetic field $H = 6700$ oersteds. The Wilson chamber, the scheme for synchronizing it with the synchrotron, and also the auxiliary apparatus are described in detail in work (^{5}). The experiments on photodisintegration of nitrogen nuclei were carried out at a maximum bremsstrahlung γ-ray energy of 90 MeV. In the working volume of the Wilson chamber there was a mixture of nitrogen and helium with partial pressures of 390 and 500 mm Hg, respectively. Such filling of the chamber was chosen in order to reduce the stopping power of the medium so as to increase the ranges of recoil nuclei. This is important for reliable identification of photodisintegrations of various types, and also for certain measurements. In addition, the helium admixture made it possible to determine the absolute yields of nitrogen photodisintegrations by comparison with the corresponding yield of the (γp) reaction on helium, which was studied in works (^{6},^{7}).

Identification of photodisintegrations was carried out on the basis of a comparison of a number of factors, such as ranges, ionization densities, track orientations, etc. Thus, for example, in identifying the (γp) and (γnp) reactions, the orientation of the tracks of the protons and recoil nuclei was taken into account both relative to one another and relative to the direction of the γ-beam. In addition, the proton energy, determined from the curvature of its track in the magnetic field, was compared with the energy determined from the range of the recoil nucleus. In the case of the (γnp) reaction these energies can differ greatly. The indicated identification method made it possible to distinguish reliably between the (γp) and (γnp) reactions, with the exception only of those cases in which the energy ratio $E_n/E_p < 0.1$. The fact that the recoil nuclei in (γnp) reactions had comparatively large ranges ($\sim$ 3 mm) made it possible to isolate cases of the (γnp) reaction in which the neutron energy was greater than the proton energy. It also proved possible to determine the emission angles of neutrons in the (γnp) reaction relative to the direction of the γ-beam, provided

Fig. 1. Energy spectra of photoprotons: 1 –reaction $N^{14}(\gamma p)C^{13}$; 2 –reaction $N^{14}(\gamma np)C^{12}$

Figure 1: Fig. 1. Energy spectra of photoprotons: 1 –reaction $N^{14}(\gamma p)C^{13}$; 2 –reaction $N^{14}(\gamma np)C^{12}$

that the neutron had an energy several times greater than that of the proton.

Table 1

Reaction	Yield, %	Threshold, MeV
γp	28	7.55
γn	15	10.55
$\gamma\alpha$	2	11.62
γnp	33	12.50
$\gamma 3\alpha np$	11	19.75
$\gamma\alpha p$	4	17.21
Other stars	7	–

The relative yields of photonuclear reactions on nitrogen are given in Table 1. These data were obtained from the processing of 2633 photodisintegration events. The total cross section for absorption of γ-quanta was found to be 9.8 ± 0.8 mbarn/Q. The experimentally determined total integral cross section for absorption of γ-quanta for N^{14}, equal to

0.3 MeV · barn, is in good agreement with the theoretical value of this quantity, 0.29 MeV · barn, calculated by the sum rule for $E1$ transitions at $x = 0.5$ (8). It should be noted that the quantitative data concerning the yields of photonuclear reactions on nitrogen obtained in (9) approximately coincide with ours.

The energy spectrum of photoprotons of the (γp) reaction is presented in Fig. 1 (histogram 1). It is seen that there is a very appreciable yield of protons

Fig. 1. Energy spectra of photoprotons: 1 –reaction $N^{14}(\gamma p)C^{13}$; 2 –reaction $N^{14}(\gamma np)C^{12}$

with relatively high energies. On the basis of the spectrum presented, the dependence of the cross section of the (γp) reaction on the energy of the γ-quanta was found, under the assumption that the recoil nuclei C^{13} remain in excited states with an energy of 3.6 MeV. The cross-section curve has a maximum at a γ-quantum energy of $\sim$ 23 MeV, and its width is more than 12 MeV. The integral cross section of the (γp) reaction is equal to 0.07 MeV · barn.

The angular distributions of protons from the (γp) reaction are shown in Fig. 2. Protons with energies from 0.4 to 50 MeV have an angular distribution that can be described by the expression $1 + 1.3 \sin^2\theta + 0.16 \cos\theta$ (curve 1), while protons with energies above 10 MeV are described by the expression $1{+}2\sin^2\theta{+}0.25\cos\theta$ (curve 2).

From comparison of the above results with calculations carried out on the basis of the Wilkinson model (10), it follows that the overwhelming part of the (γp) reactions on nitrogen is due to a direct resonance process. The observed width of the cross-section curve of the (γp) reaction can also be understood from the point of view of the Wilkinson model. Indeed, the value of the imaginary part of the optical potential for protons with an energy of 12 MeV, according to (11), is equal to 6 MeV. Let us note that, according to (10), protons with an energy of 12 MeV are due almost entirely to $p^3_{1/2} \rightarrow d_{1/2}$ transitions, whose intensity amounts to about 90% of the intensity of all possible transitions for N^{14}.

The energy spectrum of protons emitted as a result of the (γnp) reaction is shown in Fig. 1 (histogram 2). Attention is drawn to the fact that the maximum of the energy spectrum of the protons is located in the region of proton energies ~ 1.5 MeV. In this connection the following conclusion may be drawn. Since the (γnp) reaction is caused mainly by γ-quanta of the giant resonance, it follows that the neutrons must be emitted with higher energies than the protons. Indeed, as a result of the measurements it was found that in approximately 70% of the cases of the (γnp) reaction the protons possess

give a lower energy than the corresponding neutrons. It is characteristic that the angular distribution of these protons relative to the direction of the γ-beam is almost isotropic (curve 3 in Fig. 2), whereas the angular distribution of the protons belonging to the remaining 30% of the cases of the (γnp) reaction has a noticeable anisotropy (curve 4). The angular distribution of the neutrons, which have several times greater energy than the protons in the corresponding (γnp) reactions, has an anisotropic form of the type $1 + 2.2\sin^2\theta$ and is shown in Fig. 2, 5. The latter distribution resembles the angular distribution of the protons belonging to the (γp) reaction and having energies above 10 MeV.

These results can be explained if it is assumed that in the majority of cases ($\sim 2/3$) the (γnp) reaction proceeds as follows. First a neutron of relatively high energy is emitted, and then a proton from the excited nucleus N^{13}. Let us note, incidentally, that the binding energy of the proton in the nucleus N^{13} is 1.9 MeV—0.4 MeV below the energy of the first excited state of the nucleus N^{13} (12). In this connection attention should be drawn to the following circumstance. The portion of the energy spectrum of the (γnp) protons in the energy region 1.3–1.9 MeV was obtained on the basis of measuring the proton energies from their ranges, which made it possible to carry out a detailed analysis of this part of the spectrum. Apparently, the protons corresponding to this part of the spectrum belong to the second or third excited level of the nucleus N^{13}. The same conclusion can be reached on the basis of the Wilkinson model, namely: the $p_{3/2} \rightarrow d_{5/2}$ transitions have the greatest intensity. A neutron emitted as a result of a direct resonance process from the $p_{3/2}$ shell leaves the nucleus N^{13} in a weakly excited, unpaired state, which can be identified with the 3/2 level of

Fig. 2. Angular distributions

Figure 2: Fig. 2. Angular distributions

the nucleus N^{13}.

Fig. 2. Angular distributions: 1—protons (γp) with energies from 0.4 to 50 MeV; 2—protons (γp) with energies above 10 MeV; 3—protons (γnp) with energies $E_p < E_n$; 4—protons (γnp) with energies $E_p > E_n$; 5—neutrons (γnp) with $E_n \gg E_p$.

On the basis of the data obtained by us, it is possible to estimate the contribution of protons due to the "quasideuteron" mechanism of interaction of γ-quanta with nitrogen nuclei to the yield of protons with energies above 18 MeV. This contribution is very small and, in order of magnitude, is about 1%.

The data relating to other photodisintegrations of nitrogen are being processed.

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Received
16 XII 1959

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