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THE PHOTONUCLEAR REACTION $^{14}N(\gamma,pn)^{12}C$: A PROPOSAL FOR AN EXPERIMENT(*).

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SUMMARY: We propose to measure total and differential cross sections, angular and energy correlations of the reaction $^{14}N(\gamma,pn)^{12}C$ by means of a diffusion cloud chamber in order to study nucleon-nucleon correlations and dynamical reaction mechanisms.

It is well known that the photonuclear reaction (γ, pn) is very important in the study of the nucleon-nucleon correlations and of the dynamical aspects of the electromagnetic interactions with nuclei. In fact, due to the one-body character of the electromagnetic interactions, only if we introduce two-body correlations the photoemission of a p-n pair may occur. We may take into account the correlations: a) by means of Jastrow wave functions, in an independent pair approximation; b) by means of the quasi-deuteron model of Levinger.

Furthermore in electric-multipole transitions one has also to consider the coupling of electromagnetic interactions to the correlations in order gauge invariance be insured. Therefore (γ, pn) reaction below pion threshold can usefully be related to the study of nucleon-nucleon short range correlations and of gauge photonuclear correlations(1).

The experimental difficulties in measuring (γ, pn) reactions are found in the following arguments:

1) (γ, pn) cross sections is generally much smaller than (γ, p) and (γ, n) cross sections; only at high energy and in small range of energy values (γ, pn) is of the same order or larger than (γ, p) or (γ, n);

2) only in very few nuclei (γ, pn) reactions can be analysed by detecting γ activity of the residual nucleus(2) because, usually, the residual nucleus is stable;

3) coincidence measurements are still difficul to perform and it is not easy to separate the different channels of reaction.

However a great effort has been made recently to measure (γ, pn) reaction in ^{4}He with s statistics ten times higher than in the earlier experiments(3, 4)(Remember that in ^{4}He (γ, pn)d process the integrated cross section σ_0 is: $\sigma_0(\gamma, \text{pn})\ 0 \div 170$ MeV $\approx$ 12 mb MeV ($\approx$ 12% of the total)).

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The differential and total cross sections, together with angular and energy correlations fot the three-body photodisintegration of ^{4}He, have been investigated with a 38 cm diameter diffusion cloud chamber, filled at 5 atm and placed in a magnetic field, and a total of 34000 photographs have been examined.

From the theoretical point of view we have: a) He(γ, pn)d reaction aplitude have been calculated by Nouguchi and Prats$^{(5)}$ with a quasi-deuteron mechanism and the experimental results of the Torino-group are consistent with their calculations; b) Gari and Hebach$^{(1)}$ have introduced nucleon-nucleon correlations by means of mesons exchanges. The gauge contributions to the correlations give the most important contribution below pion threshold.

It is well known from the early experiments of Gorburnov et al.$^{(6)}$ and of Komar et al.$^{(7)}$ that the reaction (γ, pn) is the most important photonuclear reactions in ^{14}N in spite of having a higher threshold than the (γ, p) and (γ, n) reactions.

It is therefore justified to think that ^{14}N is the most interesting nucleus, in the overall photon energy range, in order to study nuclear correlations, in fact the (γ, pn) reaction may be measured more easily in this nucleus than in other nuclei: in ^{14}N every three events one at least is a (γ, pn) reaction.

Experimental data on ^{14}N (γ, pn)^{12}C reaction available at present are summarized as follows

	interval energy MeV	number pictures examinated	integrated cross section σ_0 mb MeV	
Gorbunov et al.	0 ÷ 170	5300	128	cloud chamber 50% N, 50% H
Komar et al.	0 ÷ 60	2633	110 ± 7	cloud chamber N+Me mixture

From harmonic oscillator sum rules$^{(8)}$ we have that electric quadrupole transitions in ^{14}N are about the 10% of the total; all the remainder transitions have principally electric dipole multipolarity. Let us remember that in the E1 transitions (γ, pp) and (γ, nn) do not give contribution.

The statistics of the Gorbunov et al. and Komar et al. experiment is too low in comparison with analogous up-to-day experiments. Komar et al. give behaviour of the cross section $\sigma(E_\gamma)$ versus the incident photon energy E_γ, while Gorbunov et al. report the integrated and energy-weighted cross sections from 0 to 170 MeV. These sum rules seem to be undervaluated respect to the Komar et al. results.

In the experimental cross section $\sigma(E_\gamma)$ of Komar et al. one can distinguish two regions: the first one has a behaviour which is about ten times the value of the photodisintegration cross section of the deuteron; the second one, situated at higher energies, is about ten times the (γ, pn) photoreaction cross section in ^{4}He. Angular and energy correlations between the emitted particles have not been measured although these data are very important in studying the mechanism of reaction.

It is therefore desiderable to perform an up-do-day (γ, pn) experiment on ^{14}N. This can be made by means of a diffusion chamber, 80 cm of length, in a magnetic field. The chamber can be filled with N mixed to H at 1/2 atm to bring down the stopping power and thus to increase the recoil range of the residual nucleus ^{12}C and to decrease the scattering of the charged particles.

Since the reaction (γ, pn) is composed of three particles, the outgoing charged particles are emitted at arbitrary angles with respect to each other and the incident photon direction.

In conclusion (γ, pn) events can be easily distinguished from the (γ, p) events: i.e. the recoil of the ^{12}C nucleus can be distinguished from the ^{13}C recoils of the (γ, p) reactions.

Theoretical work has to be done on the following problemes that can be outlined by considering the existing experimental results: a) the (γ, pn) is characterized by a non-uniform energy distribution between the proton and the neutron; b) the (γ, pn) reaction occurs in cascades: is seems that the neutron is the first nucleon to be emitted in the 75% of the cases; c) the (γ, pn) reaction can proceeds through these mechanisms:

$$^{14}N(\gamma,\ n)^{13}N^{*} \qquad\qquad ^{13}N^{*} \longrightarrow {}^{12}C + p$$

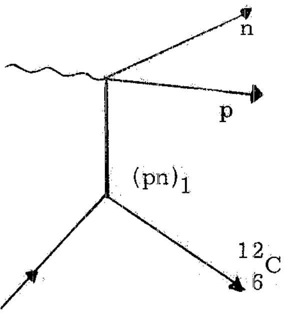
or

$$^{14}N(\gamma,\ p)^{13}C^{*} \qquad\qquad ^{13}C^{*} \longrightarrow {}^{12}C + n$$

On the other hand:

a) Kopaleishvili and Jibuti$^{(9)}$ claimed that the n-p pair in the $p^{1/2}$ subshell above the shell and subshell forming the ^{12}C plays the main rolе in the (γ, pn) reaction in ^{14}N; b) it seems that the Levinger two-nucleon mechanism of the (γ, pn) reaction is negligeable up to 90 MeV. Therefore more attention has to be devoted to the quasi-deuteron model by means of which Noguchi and Prats have been successful in describing (γ, pn) reaction in ^{4}He.

By following their work we have to calculate for the $^{14}N(\gamma,\ pn)^{12}C$ process the diagram



The amplitude of the reaction is

$$\langle pn,\ {}^{12}C \,|\, H_\gamma \,|\, {}^{14}N \rangle = \sum_{(pn)_1} \langle pn \,|\, H_\gamma \,|\, (pn)_1 \rangle \langle (pn)_1\ {}^{12}C \,|\, {}^{14}N \rangle$$

where

H_γ is the electromagnetic transition operator;

$\langle (pn)_1\ {}^{12}C \,|\, {}^{14}N \rangle$ is the amplitude for the virtual break-up of ^{14}N in a quasi-deuteron $(pn)_1$ and a ^{12}C;

$\sum_{(pn)_1}$ means integration over the momenta of the nucleons and sum over the spins.

By using the Levinger approach we have:

$$\langle pn \,|\, H_\gamma \,|\, (pn)_1 \rangle = \langle pn \,|\, H_\gamma \,|\, d \rangle \frac{f(q)}{N_d}$$

Therefore

$$\langle pn,\ {}^{12}C \,|\, H_\gamma \,|\, {}^{14}N \rangle = \sum_{(pn)_1} \frac{f(q)}{N_d} \langle pn \,|\, H_\gamma \,|\, d \rangle \langle (pn)_1\ {}^{12}C \,|\, {}^{14}N \rangle$$

where

$|\, d \rangle$ is the deuteron wave function;

$|\, (pn)_1 \rangle$ the quasi-deuteron wave function; N_d and f(q) are taken from the theory of the effective range.

We have therefore to evaluate the amplitude $\langle (pn)_1\ {}^{12}C \,|\, {}^{14}N \rangle$. Let us make use of cluster models for $^{14}N(3\alpha + d)$ and for $^{12}C(3\alpha)$. In the ^{14}N nucleus the quasi-deuteron system can be generated from the deuteron or from one of the three α particles.

We may write then:

$$\langle (pn)_1\ {}^{12}C \,|\, {}^{14}N \rangle = a \langle (pn)_1 \,|\, d \rangle + 3b \langle (pn)_1\ \ d \,|\, {}^{4}He \rangle$$

where a and b are two parameters which take into account the wave functions antisymmetrization. The first amplitude a $\langle (pn)_1 | d \rangle$ should be mostly effective on the first part (low energy) of the cross section and the second on the higher energy part ($>$30 MeV). By neglecting the amplitude $\langle (pn)_1 | d \rangle$ and taking b=1, the $^{14}N(\gamma, pn)\ ^{12}C$ integrated cross section results nine times the σ_0 value of $^4He(\gamma, pn)$ (which is, in fact, a reasonable result).

This reaction model together with the use of short range correlations allow the calculation of cross sections (differential and total) angular and energy correlations which should be compared with complete and good reliability experimental results.

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