MULTIPARTICLE PHOTONUCLEAR REACTIONS ON P-SHELL NUCLEI IN THE INTERMEDIATE ENERGY INTERVAL

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Photonuclear reactions on ^{12}C and ^{16}O with one or two nucleons in the final state have been investigated by the method of diffusion chamber in a magnetic field. The experimental results are discussed in the framework of the model of photon absorption by a nucleon pair.

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The mechanism of (γ,*np*)- and (γ,*N*)-reactions has been a subject of research interest for many years. At energy above the giant resonance the photonuclear reactions represent an effective instrument for the intranuclear correlation investigations. A study of the photon absorption mechanism by the correlated *np* pair offers a possibility to look into the problem of nucleonic interactions at small and medium distances. The phenomenological quasideuteron model has successfully explained (γ,*np*)- and (γ,*N*)-reactions at intermediate energies. By this model single-nucleon emission arises when either the proton or the neutron escapes, the other participating nucleon being reabsorbed into the nucleus through final-state interactions. One important result that confirms this point of view is the observation of the ratio $R=\sigma(\gamma,n_o)/\sigma(\gamma,p_o)$ equal to 1 for light self-conjugate nuclei. Recently, the model has got a further development in new microscopic approaches. An agreement with experimental results was achieved taking into account meson exchange currents and collective nucleus characteristics in the framework of shell model. Experimental results about of a highly excited final nuclear state formation in (γ,*np*)-and (γ,*N*)-reactions are needed to verify the prediction of the model.

The experiment was performed by the method of diffusion chamber in the magnetic field of strength 1.5 T. The chamber, filled with a mixture of methane (13%) and helium, was exposed to a beam of bremsstrahlung photons with an endpoint energy of 150 MeV. Owing to the gas filling, the tracks of slow residual nuclei had measurable lengths, and their images on a photographic film were sufficiently clear at pressures close to atmospheric one. Low density of the chamber medium and the magnetic field made it possible to measure the kinematics parameters of all charged particles and derive information about highly excited final nuclear states that decay through hadrons. A large angular acceptance permits one to measure angular distributions of multiparticle photonuclear reaction products in a broad energy range. The energy dependence of the angular distribution asymmetry for multiparticle reaction products was chosen for investigating the interaction mechanism at energies above the giant resonance.

The (γ,*np*)- reaction cross sections on ^{12}C, ^{16}O and ^{14}N nuclei were measured at energies from threshold up to 150 MeV [1,2]. The asymmetry of angular distribuions with respect to a right angle was defined in a model-independent way:

$$\beta=\left[\int_0^{\pi/2}(d\sigma/d\Omega)d\theta - \int_{\pi/2}^{\pi}(d\sigma/d\Omega)d\theta\right]/\int_0^{\pi}(d\sigma/d\Omega)d\theta. \quad (1)$$

Fig. 1 displays the asymmetries of the angular distributions of protons and neutrons [2] as functions of energy in the intervals 30-40, 40-55, 55-75, 75-100, and 100-150 MeV. With energy increasing, the asymmetry becomes more pronounced. Within errors, it takes the same value both for particles from the different reactions and for nucleons from the same reaction. This result can be expected within the model of photon absorption by the *np* pair. The full curve represents the asymmetry calculated for A(γ,*np*)(A-2) kinematics within the quasideutron model. This result satisfactorily reproduces experimental data at energies above 40 MeV.

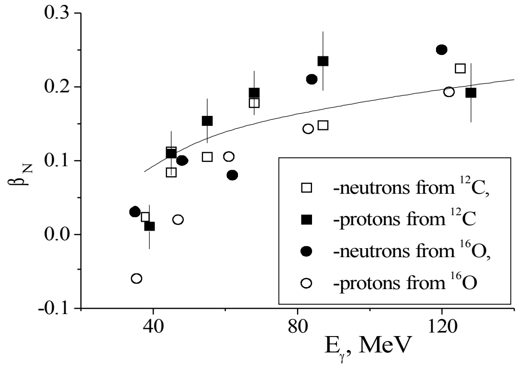

Fig. 1. *Nucleon angular distribution asymmetry β_N as a function of photon energy*

In the model of photon absorption by a nucleon pair, the residual nucleus is a spectator. Therefore, it is natural to expect that its angular distribution will be isotropic in the laboratory frame. The asymmetry of the angular distributions of residual nuclei in the laboratory frame is shown in Fig.2 as a function of energy [2]. This asymmetry is nonzero over the entire energy interval and, within errors, takes the same value for the two reactions. At the energies excess of 40 MeV the asymmetry changes weakly with increasing energy. In region of intermediate energies, there are FSI-induced distortions in the A(γ,*np*)(A-2) reaction. In the quasideutron model, the asymmetry of the angular distribution of residual nucleus can be due to FSI: nucleons traveling predominantly in the forward direction transfer a part of their momentum to a residual nucleus. The calculation within the quasideuteron model that takes into account FSI in the simplest form (see the curve in Fig. 2) satisfactorily describes the experimental data.

Five multiparticle reactions were investigated in the energy interval from their threshold up to 150 MeV:

1. a) $\gamma+^{12}C\to p+^{11}B_0$, b) $\gamma+^{12}C\to p+^{11}B^*\to ^{11}B_0+\gamma'$,

2. a) $\gamma+{}^{16}O \to p+{}^{15}N_0$, b) $\gamma+{}^{16}O \to p+{}^{15}N^* \to {}^{15}N_0+\gamma$,

3. $\gamma+{}^{12}C \to p+{}^{11}B^* \to \alpha+{}^{7}Li$,

4. $\gamma+{}^{12}C \to n+{}^{11}C^* \to \alpha+{}^{7}Be$,

5. $\gamma+{}^{12}C \to p+{}^{11}B^* \to t+\alpha+\alpha$.

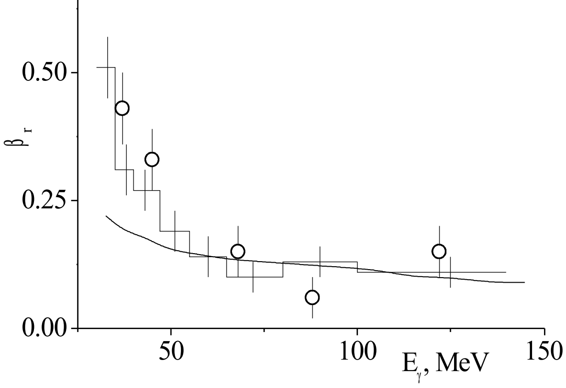

Fig. 2. *Asymmetry β_r (l.s.) vs energy. Experimental data are represented by the histogram and points for the reactions $^{12}C(\gamma,pn)^{10}B$ and $^{16}O(\gamma,pn)^{14}N$, respectively. The curve is explained in the text*

It has been found that multiparticle reactions go through a two-particle stage. Energy characteristics of intermediate excited nuclear states were specified. The excited states formed in reactions (3)-(5) have broad maxima. The first two reactions were analyzed without separation into channels.

Fig. 3 shows the asymmetry coefficient of the nucleon angular distribution as a function of energy. With energy increasing, the asymmetry coefficient also quickly grows. Within errors, it takes the same value both for protons and neutrons.

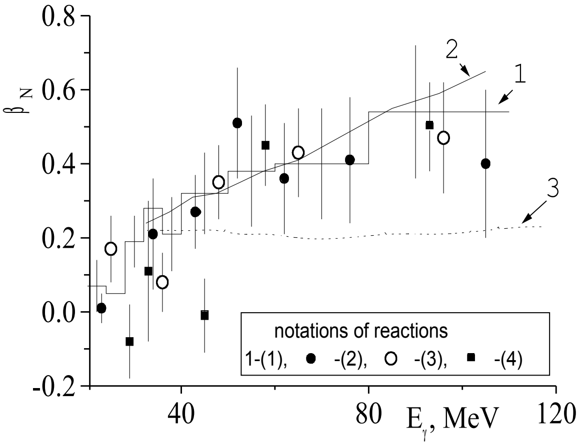

Fig. 3. *Asymmetry β_N vs energy in the laboratory frame, curves are explained in the text*

This result can be expected within the model of photon absorption by an *np* pair. Curve 2 represents the asymmetry calculated within the quasideuteron model. Curve 3 shows the asymmetry obtained for free-deuteron photodisintegration.

Fig. 4 displays the asymmetry of the nucleon angular distributions as a function of intermediate nuclear excitation energy when the γ-quanta energy equals 80 MeV [4]. The asymmetry of angular distributions of nucleon photoproduction when the intermediate nucleus remained in the ground or low excited state were derived from literary data by substituting the experimental data [5-6] into (1). All the data manifest the dependence of the asymmetry coefficients on the excitation energy of the intermediate nucleus. The curve shows the asymmetry calculated within the quasideuteron model.

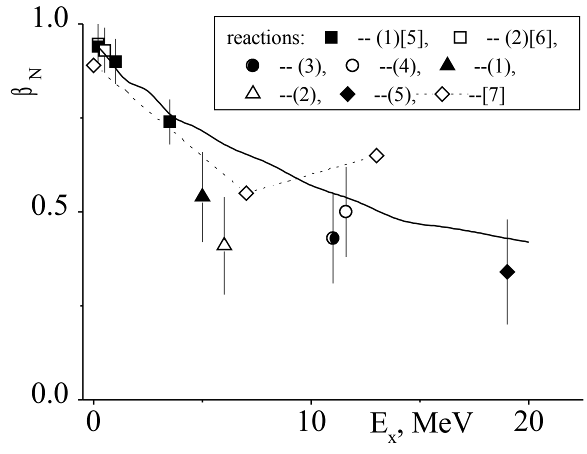

Fig. 4. *Asymmetry β_N as a function of intermediate nuclear excitation energy*

Recently, a considerable progress in description of the data has been achieved by incorporating the effects of meson-exchange currents and the coupling of the initial and final states in to the giant resonance [7]. The diamonds and the doted curve represent the asymmetry obtained by substituting the calculated angular distribution in the $^{12}C(\gamma,p)^{11}B$ reaction from [7] for E_x = 0.0, 7.0 and 13 MeV into (1). The (γ,p) process is dominated by pion exchange currents if E_x=13 MeV. The ground-state data are better described by the random phase approximation (RPA) model that includes multistep processes and meson exchange currents [7]. There is an agreement with the experimental data.

The experimental results are in agreement with the model of the γ-quantum absorption by the nucleon pair.

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