CALCULATION OF THE CROSS SECTION FOR THE REACTION $\gamma^3\mathrm{He}\to\ \mathrm{pd}$ AT INTERMEDIATE PHOTON ENERGIES

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The differential cross section and the asymmetry coefficient for the two-body photodisintegration of ^{3}He by linearly polarized photons are calculated with wave functions for Bonn potential. Dependences of the observables on the components of the ^{3}He wave function with the orbital angular momenta L, l $\geq$ 1 are studied at photon energies E_γ up to 300 MeV.

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Mechanisms of the reaction $\gamma\,^3$He→pd and proton-deuteron radiative capture at intermediate energies were explored in Refs. [1-9]. In these articles 3N bound state wave functions (WFs) for realistic nucleon-nucleon potentials were used and plane wave approximation for pd-system was accepted. Role of rescattering effects was studied only in restricted area of photon energies $E_\gamma \leq 139.1$ MeV [10-12]. While calculations [1-6,9] were performed with Hannover-Helsinki WF [13] for the Reid soft core (RSC) potential, recent investigations [10-12] were carried out with the rigorous solutions of the 3N Faddeev equations for modern models of nuclear forces, e.g., Argonne, Nijmegen and CD-Bonn potentials.

Consistency of the interaction currents and the model of nuclear forces was shown to be important [3, 4, 6, 9, 11, 12] in calculations of cross sections and polarization observables. Thus, meson exchange currents (MEC) for Argonne potential were used in [11,12] to respect the requirement of gauge independence of the reaction amplitudes.

Along with the relativistic effects originated from meson exchange, manifestation of the spin-orbit electromagnetic interaction of nucleons was studied in [9,14]. It was demonstrated that inclusion of the spin-orbit current (SOC) led to increase of Σ values reducing divergence between theory and experiment at $E_\gamma > 100$ MeV.

Role of gauge invariance and Lorentz covariance was studied in [15,16] where a model to account for a part of MEC contributions and the pd-rescattering effects was suggested. By construction [15,16] the reaction amplitudes satisfy the continuity equation. The amplitudes are expressed in terms of pd^{3}He vertex function and pd scattering phase shifts.

The aim of the present work is to extend calculations [3, 4, 6, 9, 14] taking advantage of the precise numerical solution of the Faddeev equations for the ^{3}He WF obtained by Bochum-Cracow group [17-19] for Bonn potential and to inquire into dependence of the differential cross section and the asymmetry coefficient on the WF components considering the reaction at intermediate energies $E_\gamma \leq 300$ MeV.

The amplitudes of the reaction are calculated within approach [3, 4, 6, 9, 14] without any multipole expansion for the nuclear current. The contributions of the MEC are expressed in terms of six-dimensional integrals evaluated numerically.

The Riska model of the π-meson exchange currents (πEC) is used for the two-body part of the nuclear current. The pion-nucleon form factors in MEC are taken in the monopole form with the cut-off parameter Λ_π=1.2 GeV/c.

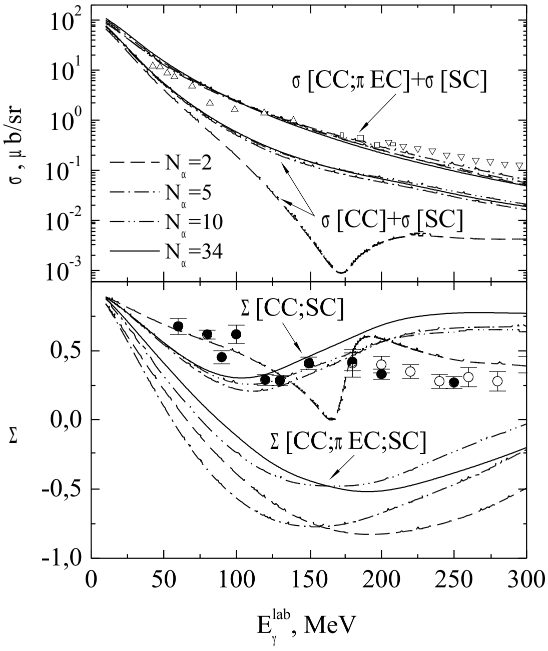

Fig. 1. *The differential cross section* $\sigma = d\sigma / d\Omega_p^{cm}$ *for* ^{3}He(γ, p)d *and the asymmetry coefficient for the reaction with linearly polarized photons at a proton emission angle* θ_p^{cm}*=90°. The experimental data* □,., □,. *and* ˜ *are taken from [20, 7 ,8, 1, 2, 5] and [21], respectively*

The results obtained with Bochum-Cracow WFs [17-19] for Bonn potential are shown in Figs. 1 and 2 for different sets of the partial wave components in the ^{3}He WF. The number of the partial wave channels taken into account in decomposition of the WF is N_α, where α denotes quantum numbers in (jJ)-coupling (see, e.g., [19]). Two S-waves are retained in the decompositions of the WF for N_α = 2, D-waves with the orbital angular momenta L l=20, 02, 22 are turned on in the case of N_α = 5, P-waves for total angular momentum in the two-body subsystem J=0,1 are added in the set N_α = 10. The set N_α = 18(34) includes the components with J £2 (4) and positive parity.

As is seen from Fig. 1, the energy dependence of the cross section σ, obtained with convection current (CC), spin current (SC) and S-waves in the ^{3}He WF, has deep minimum near E_γ^{lab} = 172 MeV. This distinctive feature of σ[CC;SC;N_α=2] is observed in the angular dependence displayed in Fig.2 as well. Note, that in plane wave approximation σ[CC;SC]≡ σ[CC] + +σ[SC] [6,9].

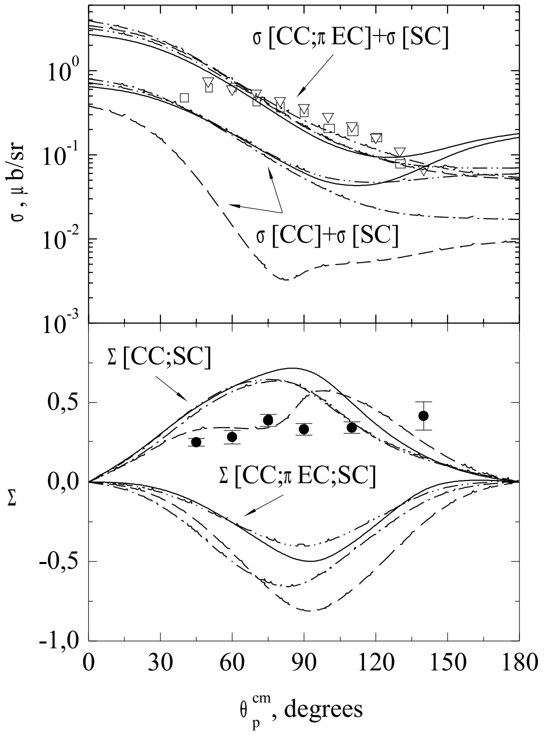

Fig. 2. *Angular distribution of the differential cross section and the asymmetry coefficient at* E_γ^{lab} = *208 MeV. Notation for the curves is the same as in Fig. 1. Points▯ and ▯ are taken from [7] and [8]. Data▯ were obtained in [1, 2, 5] at* E_γ^{lab} *= 200 MeV*

MEC smooth both the energy and angular distributions of the cross section σ[CC;SC;N_α=2] filling these minima. The appreciable difference between the values of σ[CC;SC]=8.85·10^{-4} μb/sr for N_α=2 and 9.88·10^{-2} μb/sr for N_α=34 in minimum at E_γ=172 MeV and $\theta_p^{cm} = 90^o$ is substantially reduced when πEC are included. Really, we have σ[CC;πEC;SC] =0.433 μb/sr and 0.384 μb/sr, for N_α=2 and N_α=34, respectively. One can arrive at conclusion that contributions of MEC increase the differential cross section at $\theta_p^{cm} = 90^o$ mainly due to absorption of photons by neutron-proton pairs moving with relative angular momentum equal to zero.

The beam asymmetry depicted in lower panels of Figs. 1-4 is defined as Σ=(σ▯▯-σ▯)/(σ▯▯+σ▯), where the cross section of the reaction with photons polarized in the reaction plane (perpendicular to the plane) is denoted by σ▯▯(σ▯).

The asymmetry Σ[CC;SC] as a function of photon energy changes qualitatively when D-wave states are added to S-wave ones (cf. curves for N_α=2 and N_α=5 in Fig. 1). Sensitivity of Σ to the partial waves with α>2, unlike to the case of the cross section, survives after inclusion of the πEC.

Reducing to some extent the discrepancies between calculated and measured values of the cross sections (Figs. 1 and 2), πEC change the sign of the asymmetry in a vide energy region that is at variance with Kharkov [1,2,5] and Frascati [21] data.

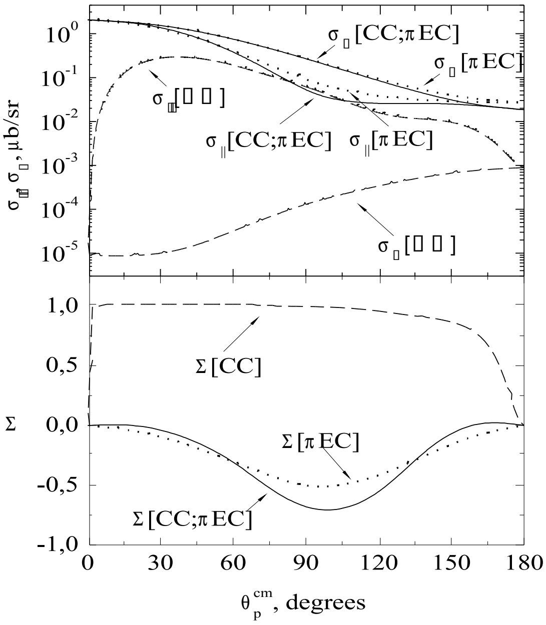

Fig. 3. *Relative role of CC and πEC in angular distributions of σ▯▯, σ▯ and the asymmetry coefficient at* E_γ^{lab} *= 208 MeV*

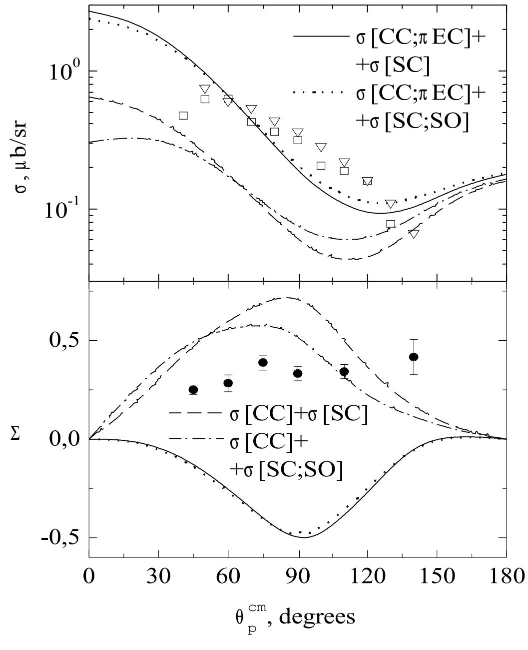

Fig. 4*. The same as in Fig. 2. Shown are effects of the spin-orbit electromagnetic interaction with nucleons*

As is known [9,14] neither pionic nor seagull MEC interfere with SC or SOC when final state interaction (FSI) is neglected. Coherent contributions of CC and πEC are plotted in Fig. 3. Influence of CC on σ⊥ is very small and σ

$_\perp$ is entirely determined by πEC. Comparison of angular distributions of σ calculated with full inclusion of the rescattering effects [11,12] with results obtained in plane wave approximation indicates the great importance of the effects of FSI at energies E_γ~70-130 MeV. One can infer that FSI compensates increase of the cross section due to MEC. So, it can be expected that the destructive interference of FSI and MEC can affect the asymmetry coefficient changing its behavior.

Following [9, 14], the SOC has been included into present calculations. Inclusion of MEC results (see Fig. 4) in considerable decrease of relative role of the SOC effects. It turns out that influence of SOC can be enhanced if one uses ‘soft’ pion-nucleon form factors with cut-off parameter, e.g., $\Lambda_\pi=4m_\pi$ (the corresponding curves are not shown here). However, the Riska model of πEC with $\Lambda_\pi=4m_\pi$ is hardly consistent with Bonn potential since Λ_π=1.3 GeV/c is chosen in the later. It should be noted that according to our calculations variations of the cut-off parameter in the interval $1.2\leq\Lambda_\pi\leq1.3$ GeV very slightly modify the values of the observables within the energy region discussed.

In summary, it is demonstrated that πEC manifest themselves mainly in transitions from the S-states of ^{3}He ($N_\alpha=2$) substantially increasing the cross section values. Angular distributions of the cross section at θ_p^{cm}□ 120° are insensitive to inclusion of partial wave components of ^{3}He WF with the orbital angular momenta L,l>0 ($N_\alpha>2$).

The relative role of the states with α>2 is enhanced in the case of the asymmetry coefficient. This observation allows one to hope that reaction $\gamma\ ^3\mathrm{He}\rightarrow$ pd with linearly polarized photons provides a strict and sensitive testing ground for exploring structure of 3N bound state. Surely, consideration of relevant reaction mechanisms, first of all, the rescattering in the final pd-state and three-nucleon photoabsorption is of great interest for interpretation of the data both for the cross section and the asymmetry coefficient.

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