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AMPLITUDES OF ^{3}H, ^{3}He TWO-PARTICLE PHOTO-BREAKUP IN NON-LOCAL QED APPROACH†

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Three-nucleon systems are essential for the investigation of many-body forces in nuclear physics. Well-grounded parametrization of their vertex functions with further application for the calculation of cross-sections in nonlocal QED approach provides the ground for investigation of the variety of multi-particle systems. In present paper we describe the process of parametrization of two-particle photo-breakup amplitudes of three-nucleon systems (^{3}H, ^{3}He). We provide the general description of the wave function construction for three-nucleon systems as well as the parametrization of their vertex functions accounting two- and three-nucleon interactions based on meson exchange current formalism. In our calculations we account first and second order one-pion exchange terms and the term related to the exchange of ω and ρ mesons. The three-nucleon interaction potential is given as a sum of attraction (two-pion exchange) term and appropriate repulsive part. Based on the variational "Urbana + Model VII" amplitudes we provide the results for energy dependence of differential cross-section of $^3He(\gamma,p)d$ reaction at proton angle $\theta = 90^\circ$ from the threshold up to $E_\gamma =$ 40 MeV and compare theoretical predictions with the available experimental data. The investigation is also provided for angular cross-section distributions at high photon energies ($E_\gamma = 305 \pm 5$ MeV; 365 ± 5 MeV; 450 ± 10 MeV and 675 ± 50 MeV). Correct description of ^{3}H, ^{3}He photo-disintegration processes in a unified approach based on the gauge nature of the electromagnetic field implies application of this model for other multi-particle systems.

Keywords: *Three-nucleon system; Photo-breakup; Cross-section; Amplitude; Many-body force; Meson-exchange current*

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1. INTRODUCTION

The main goal of studying multi-particle systems in nuclear physics is to obtain the most complete description of the interactions between nucleons. This question is still open, while the charge independence of nuclear forces is a well-established fact both at low and high energies. In most cases, theoretical methods applied to multi-particle systems are extensions of the well-studied two-body problem. The most sensitive candidate for obtaining information about pure nuclear interactions is the binding energy of the tritium and helium-3 nuclei. Such information can be obtained through the study of three-nucleon systems in the presence of electromagnetic and weak interactions. In other words, one of the sources of information about sub-nuclear interactions is the electromagnetic breakup processes and the investigation of momentum distributions of constituent sets corresponding to different structural levels of matter. It's worth noting that a satisfactory analytical expression for the nuclear potential, covering the entire energy scale inside the nucleus, currently does not exist. At this stage, questions arise about the construction of the wave function components, which can be addressed based on the meson-exchange current (MEC) formalism.

Three-body systems are the simplest multi-particle systems. Essentially, they don't have a simple analytical solution (as in the two-body case) and their behavior cannot be predicted using statistical methods (as in the multi-particle case). Extending the two-body approximation to the three-body case can provide qualitative information about the importance and nature of three-body forces. The idea that there might exist a force between three bodies that cannot be represented as a sum of two-body interactions has no analogy in classical physics. However, there are indications that three-body forces might play an important role in nuclear physics. For instance, Brown and Green [1] in 1969 suggested that about 2 MeV of nuclear binding energy arises due to the presence of a specific multi-particle force. There are indications that the contribution of three-body forces to the behavior of strongly interacting three-nucleon systems must be significant, particularly proportional to the magnitude of the recoil in the ground state when the emitted particle has electromagnetic nature.

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2. CONSTRUCTING THE WAVE FUNCTION OF A THREE-NUCLEON SYSTEM

The usual spin and isospin dependence of nuclear forces in three-particle systems introduces algebraic issues that can be easily overcome. On the other hand, the short-range nature of nuclear interactions incorporates a more complex problem, which involves approximating complex wave functions with trial functions that have a simple analytical expression.

The presence of non-central forces significantly complicates the wave function of a three-nucleon system. In reality, for such systems, there are only three absolute quantum numbers. These are the quantum number of total angular momentum ($J = 1/2$), parity ($\uparrow\uparrow$), and isospin ($T = 1/2$). However, if central forces are represented as a "mixture" of usual (Wigner) and spatial-exchange (Majorana) forces, then permutations of spatial positions of particles within the nucleus are allowed. These generate additional quantum numbers associated with the invariance of the wave function with respect to such permutations. A three-nucleon system can have only three such quantum numbers (three irreducible representations of the permutation group of three objects). There are completely symmetric, completely anti-symmetric, and one "mixed" representation.

Thus, the charge independence of nuclear forces yields three possible states $^2S_{1/2}$. The dominant state for a three-nucleon system under the influence of central forces is the symmetric S-state (with a probability of around 90%), such that $L = 0$, $S = 1/2$ and the wave function is fully symmetric. In this work, we will limit our consideration to this state. In turn, the "mixed" state is typically denoted as S'. The probability of this state does not exceed 1-2%.

For three-particle systems, the theory starts with 9 coordinates describing the position of each of the three particles $\mathbf{r_1}(x_1, y_1, z_1), \mathbf{r_2}(x_2, y_2, z_2), \mathbf{r_3}(x_3, y_3, z_3)$. The center-of-mass symmetry reduces the task to 6 coordinates. These coordinates are defining the size and shape of the triangle formed by the three nucleons. For instance, these could be the three sides of the triangle (r_{12}, r_{23}, r_{31}) and the three Euler angles $(\alpha, \beta, \gamma$), determining the orientation of this triangle in space relative to some standard orientation. Invoking symmetry groups eliminates the need to write explicit angular dependence in wave functions. This leads to transitioning from a set of six independent partial differential equations to a set of sixteen coupled equations involving only three independent variables. It's evident, that finding the solution for such a set of equations inevitably leads to the application of variational calculus.

Based on the above, the wave function of the ground state should be written as a sum of products, each containing three factors: inner wave function (A factor depending on the lengths of the triangle sides); angular" part of the wave function (factor depending on the Euler angles, determining the triangle's position in space); "spin-isospin" part of the wave function (A factor depending on the spin and isospin functions of each nucleon). At present paper we attempt to define the first two parts of the total wave function, as long as the second and third factors can be combined using Clebsch-Gordan coefficients into a single term.

For the triangle sides, the following notations can be used: $x_1 = r_{23}$; $x_2 = r_{31}$; $x_3 = r_{12}$. Permutation of particles 1 and 2 leads to the permutation of $x_1 \to r_{31} = x_2$, $x_2 \to r_{23} = x_1$, while leaving unchanged $x_3 \to r_{12} = x_3$. Thus, the permutation of particles corresponds to the permutations between $x_1; x_2; x_3$. An arbitrary function $f(x_1, x_2, x_3)$ can be symmetric, antisymmetric, or can belong to a mixed representation of the permutation group of three objects. In the simplest case, when there's only one function $u(x)$, we can create only a symmetric function of the product $f(x_1, x_2, x_3) = u(x_1)u(x_2)u(x_3)$. Having two functions $u(x)$ and $v(x)$ allows creating both symmetric and "mixed" states. An example of such a state can be found in [19]. Finally, with 3 functions, one can create a state:

$$f(x_1, x_2, x_3) = det \begin{bmatrix} u(x_1) & u(x_2) & u(x_3) \\ v(x_1) & v(x_2) & v(x_3) \\ w(x_1) & w(x_2) & w(x_3) \end{bmatrix} \tag{1}$$

which refutes the assertion that there is no antisymmetric S-function for three-nucleon systems. However, there is an evidence [2] that such a state is not observed in the ground state of a three-nucleon system.

3. PARAMETERIZATION OF THREE-NUCLEON SYSTEM VERTEX FUNCTIONS

To parameterize the vertices of strong interaction, we follow the works [4], [5] where for the nuclei ^{3}H and ^{3}He the results of variational calculations are presented for "Urbana+Model VII" and "Argonne+Model VII", as well as Faddeev calculations for the "Argonne+Model VII".

We start from the solution of 3-body Schrödinger equation:

$$H\Psi = E\Psi \tag{2}$$

$$H = \sum_{i=1,3} -\frac{\hbar^2}{2m}\nabla_i^2 + \sum_{i<j\leq 3} v_{ij} + \sum_{i<j<k\leq 3} V_{ijk} \tag{3}$$

where the potentials v_{ij} and V_{ijk} describe the two- and three-nucleon interactions, respectively. In many-body calculations for nuclei and nuclear matter, two-nucleon interactions are commonly expressed in the form of an operator:

$$v_{ij} = \sum_p v^p(r_{ij}) O^p_{ij} \tag{4}$$

where $v^p(r_{ij})$ are functions of distances between particles, and O^p_{ij} is represented as a set of operators. The model currently takes into account fourteen different operators. For the radial functions ,we use the expansion:

$$v^p(r_{ij}) = v^p_\pi(r_{ij}) + v^p_I(r_{ij}) + v^p_S(r_{ij}) \tag{5}$$

which includes one-pion exchange in the first and second-order (terms $v^p_\pi(r_{ij}); v^p_I(r_{ij})$) as well as exchange of ω and ρ mesons (term $v^p_S(r_{ij})$). For one-pion exchange in the first order the non-zero terms are related only to $(\sigma_i\sigma_j)(\tau_i\tau_j)$ and $\mathbf{S_{ij}}(\tau_i\tau_j)$ operators. They are chosen as:

$$v_\pi^{(\sigma_i\sigma_j)(\tau_i\tau_j)}(r) = 3.488\frac{e^{-\mu r}}{\mu r}(1 - e^{-cr^2}) \tag{6}$$

$$v_\pi^{\mathbf{S_{ij}}(\tau_i\tau_j)}(r) = 3.488(1 + \frac{3}{\mu r} + \frac{3}{(\mu r)^2})\frac{e^{-\mu r}}{\mu r}(1 - e^{-cr^2})^2 \tag{7}$$

where $\mu = 0.7fm^{-1}$.We note that selecting the multiplier $(1 - e^{-cr^2})^2$ stimulates the ρ-meson exchange effect. Denoting $\frac{e^{-\mu r}}{\mu r}(1 - e^{-cr^2})^2 = Y_\pi(r)$ and $(1 + \frac{3}{\mu r} + \frac{3}{(\mu r)^2})\frac{e^{-\mu r}}{\mu r}(1 - e^{-cr^2})^2 = T_\pi(r)$ the potentials for one-pion exchange in the first order can be rewritten as:

$$v_\pi^{(\sigma_i\sigma_j)(\tau_i\tau_j)}(r) = 3.488 Y_\pi(r) \tag{8}$$

$$v_\pi^{\mathbf{S_{ij}}(\tau_i\tau_j)}(r) = 3.488 T_\pi(r) \tag{9}$$

One-pion exchange in the second order is chosen in form:

$$v^P_I(r) = Ii^p T^2_\pi(r) \tag{10}$$

Such a choice of v^P_I facilitates accounting of three-nucleon interactions.

The exchange of ω and ρ mesons is taken as a sum of two Woods-Saxon potentials. This choice is dictated by the fact that the size of nucleons must be at least of the order of the Compton wavelength of ω and ρ mesons. Thus:

$$v^P_S(r) = S^p W(r) + S'^p W'(r) \tag{11}$$

where $W(r) = \frac{1}{1+e^{\frac{r-R}{a}}}$ and $W'(r) = \frac{1}{1+e^{\frac{r-R'}{a'}}}$. The values of parameters c, I^p, S^P, S'^p are obtained from phase shift analysis and presented in [7].

Three-nucleon interactions are described by the potential V_{ijk}. It's expressed as:

$$V_{ijk} = V^{FM}_{ijk} + V^R_{ijk} \tag{12}$$

where V^{FM}_{ijk} is the Fujita-Miyazawa three-nucleon interaction potential due to a two-pion exchange. It describes attraction and can be written as:

$$V^{FM}_{ijk} = \sum_{cyc} -0.0333\{(\tau_i\tau_j), (\tau_i\tau_k)\}\{x_{ij}, x_{ik}\} + \frac{1}{4}[(\tau_i\tau_j), (\tau_i\tau_k)][x_{ij}, x_{ik}] \tag{13}$$

where $x_{ij} = S_{ij}T_\pi(r_{ij}) + (\sigma_i\sigma_j)Y_\pi(r_{ij})$. In turn, V^R_{ijk} describes repulsion and is expressed as:

$$V^R_{ijk} = \sum_{cyc} U_0 T^2_\pi(r_{ij}) T^2_\pi(r_{ik}) \tag{14}$$

where the coefficient $U_0 = 0.0038$.

All calculations are performed using the Monte Carlo simulation method based on realistic Hamiltonians that consider both two-nucleon and three-nucleon interactions. These Hamiltonians provide satisfactory binding energies and densities for light nuclei and nuclear matter. We mark that the results of calculations for $d + p$ momentum distributions in ^{3}He nucleus at low momentum transfers are in good agreement with the results of electron scattering analysis in the plane-wave impulse approximation. However, the values observed at high momentum transfers are slightly larger for the chosen approach.

The variational wave function Ψ_v is expressed as a symmetric product of correlation operators. Indeed, in the case of central forces, the ground state is the S-state, which is described by a spherically symmetric wave function. The ground $^2S_1$state is symmetric with respect to the spatial coordinates of the nucleon pair and anti-symmetric with respect to their spins. It has the form:

$$\Psi_v = \{S\prod_{i<j} f^c(r_{ij})(1+\sum_p(\prod_{k\neq j} f^p_{ijk})u^p(r_{ij})O^p_{ij})\}\Phi \tag{15}$$

where S is symmetrizer, and the factor $\prod_{k\neq j} f^p_{ijk}$ reflects the effect from other particles in u^p. Correlations induced by the Coulomb potential are neglected, so $F_{ij} = f^c(r_{ij})(1+\sum_p u^p(r_{ij})O^p_{ij})$ are identical for ^{3}He and ^{3}H nuclei. The pair correlation F_{ij} can be rewritten as:

$$F_{ij} = f^c_{ij}(1+u^\sigma(r_{ij})\sigma_i\sigma_j + u^{t\tau}(r_{ij})S_{ij}\tau_i\tau_j). \tag{16}$$

It contains central f^c_{ij}, tensor $u^{t\tau}(r_{ij})$, and spin $u^\sigma(r_{ij})$ correlations.

The behavior of correlation functions at large r in three-nucleon systems is determined by considering the decay of the investigated nucleus. For instance, denoting R as the distance between selected nucleon an the center of mass of the system and considering the wave function in the region where R is large, the wave function for $^3H \to d+n$ is determined from the formula:

$$\Psi(d+n;R\to\infty) = \frac{e^{-k'R}}{R}[Y^{\frac12\frac12}_{0\frac12} + x(1+\frac{3}{K'r}+\frac{3}{(K'r)^2})Y^{\frac12\frac12}_{2\frac32}] \tag{17}$$

where x is asymptotic ration of D-wave and S-wave, K' can be found from the equation $\frac{3\hbar}{4m}K'^2 = E_d - E_t$ and Y^{LS}_{JM} represent spin and angular wave functions.

The dependence of the variational wave function at large R is given by:

$$\Psi_v(d+n;R\to\infty) = [f^c(R)]^2\{[1-4u^\sigma(R)]Y^{\frac12\frac12}_{0\frac12} + u^{t\tau}(R)Y^{\frac12\frac12}_{2\frac32}\} \tag{18}$$

assuming three-particle f^p_{ijk} factor to be unity.

By comparing (17) and (18) we finally obtain $f^c(r\to\infty)$, $u^\sigma(r\to\infty)$ and $u^{t\tau}(r\to\infty)$. The explicit forms of the spin and angular wave functions: $Y^{\frac12\frac12}_{0\frac12}$ and $Y^{\frac12\frac12}_{3\frac32}$ are taken from [2].

4. RESULTS AND DISCUSSION

Denoting $\Psi_2(m_d, \mathbf{r_1})$ as the wave function of the deuteron with spin projection m_d, and $\Psi_3(m_3, t_3)$ as the ground state of the three-nucleon system with spin and isospin projections m_3 and t_3 we can define the two-particle amplitude $A_{dp}(m_d, m_p, m_3, \mathbf{k})$ as follows:

$$A_{dp}(m_d,m_p,m_3,\mathbf{k}) = \sqrt{\frac{3}{N_1N_2}}\int d\mathbf{r_1}..d\mathbf{r_3}\Psi^\dagger_2(m_d,\mathbf{r_{12}})\chi^\dagger(3,m_p,\frac12)e^{-i\mathbf{k}(\mathbf{r_3}-\mathbf{R_{12}})}\Psi_3(m_3,\frac12) \tag{19}$$

The square of the amplitude gives the probability of the deuteron and protonto be in states m_d and m_p and a relative momentum $\mathbf{k}$ in the ground state of ^{3}He. In formula (19) the effect of antisymmetrization of the d+p state is contained in the multiplier $\sqrt{3}$. Antisymmetrization introduces a factor $\sqrt{\frac13}$ for the normalization and a factor of 3, which takes into account that any nucleon number can act as a proton. Expanding plane waves using Bessel functions, we obtain:

$$A_{dp}(m_d,m_p,m_3,\mathbf{k}) = \sum_{l,m}(-i)^l A^{lm}_{dp}(m_d,m_p,m_3,k)Y_{lm}(\mathbf{k}) \tag{20}$$

The angle averaged $d+p$ momentum distribution in ^{3}He is given by:

$$N_{dp}(k) = \frac{1}{4\pi}\sum_{m_d,m_p,l,m}|A^{lm}_{dp}(m_d,m_p,m_3,k)|^2 \tag{21}$$

The results of the calculations of the two-particle amplitudes are taken from [4]. In general, it's evident that variational and Faddeev calculations yield quite similar results. This fact points to the equivalence of Faddeev and variational calculations. However, we note that a slight difference in momentum distributions obtained from the Urbana and Argonne models is primarily due to the difference in radii obtained in these models. Nevertheless, the binding energy is not very sensitive to changes in radius, and therefore the accuracy

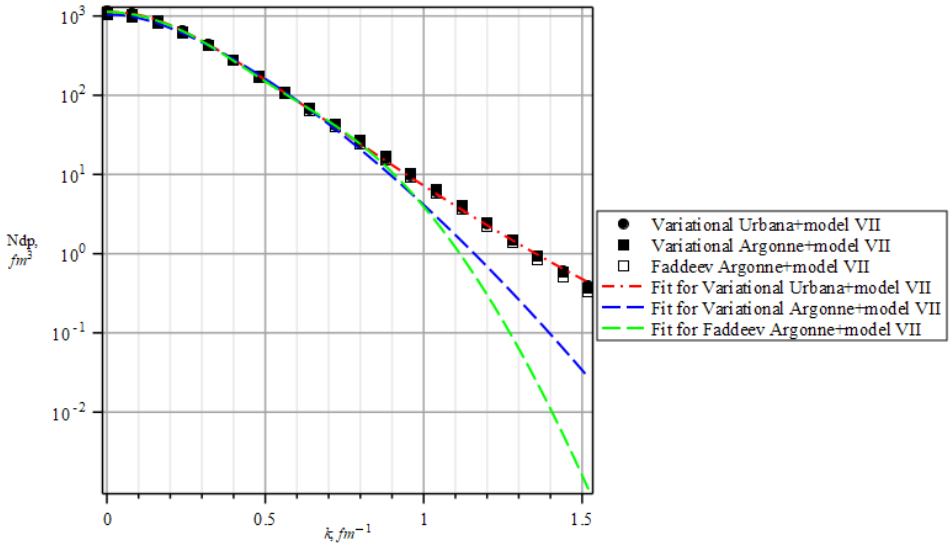


Figure 1. ^{3}He two-body N_{dp} amplitudes in fm^3.

of variational calculations for computed radius is not very high. The error in the calculations is comparable to the difference between the radii obtained from different models, which suggests that differences in results between the two models are only related to approximation in the calculations. Here we present the results of calculations with the variational "Urbana+Model VII" and "Argonne+Model VII" and for Faddeev calculations in "Argonne+Model VII" amplitude N_{dp} of ^{3}He ploted on Figure 1.

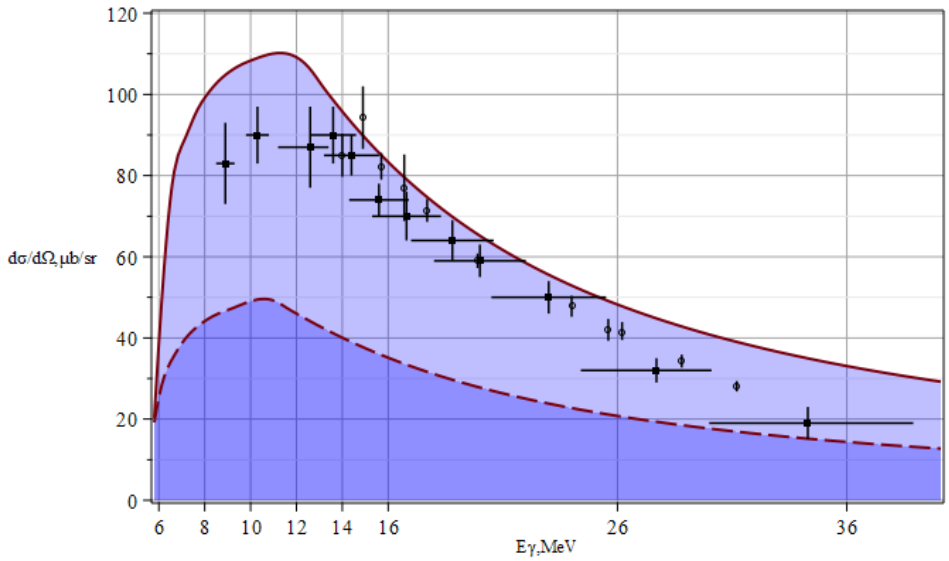
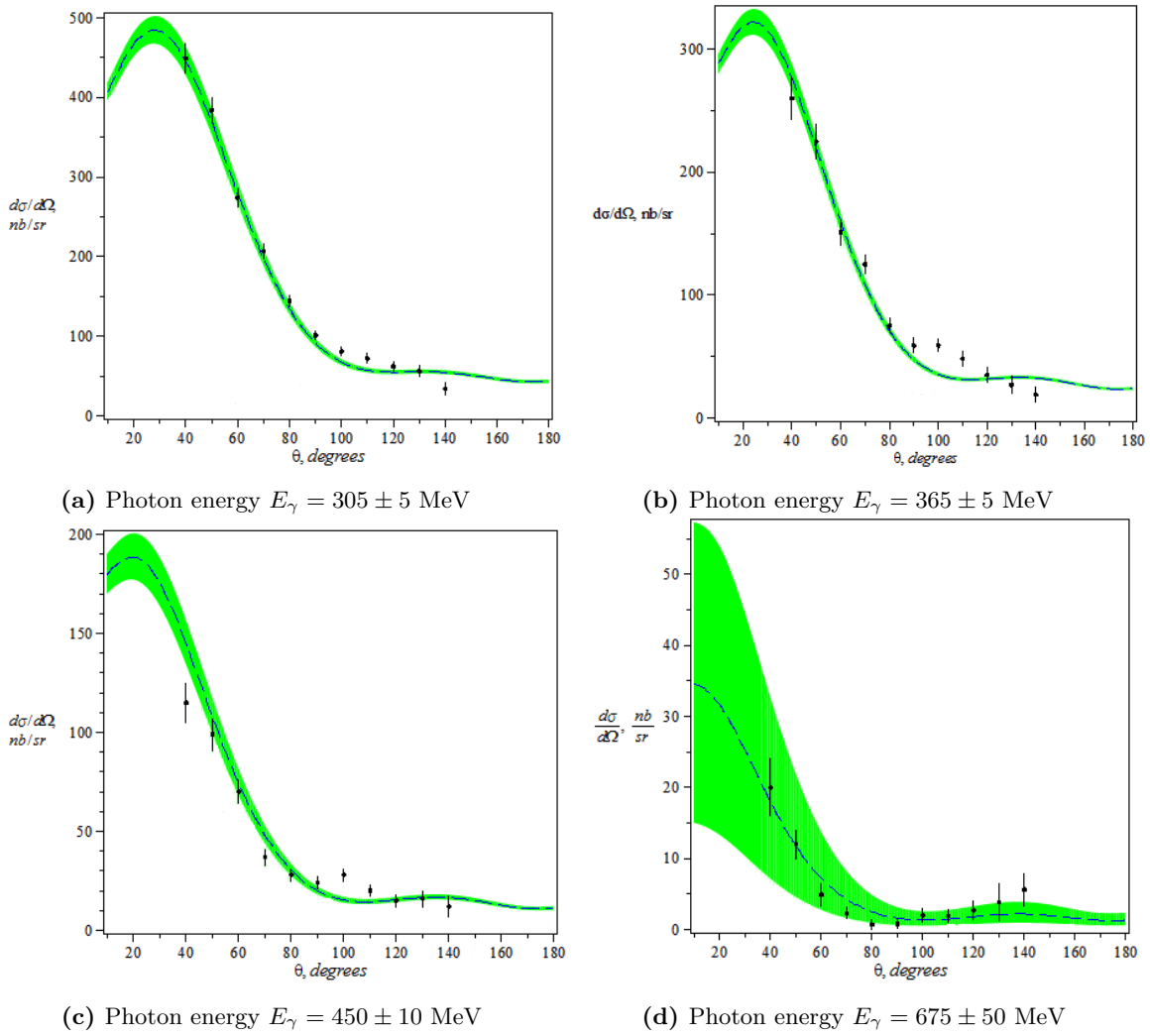


Figure 2. The energy ($\theta = 90°$) dependence of the differential cross-section of the process $\gamma + ^3He \to p + d$ from the threshold up to 40 MeV in photon energy. Experimental data are taken from [13], [14].

On Figure 2 the energy dependence of the differential cross-section is shown for the helium-3 nucleus with the proton's emission angle in the center-of-mass system equal to 90 degrees. The solid line represents the results of theoretical calculations. The dashed line represents calculations without accounting the non-local contact part of the diagram [10]. We provide the comparison of calculations for the approach, developed by authors in [8] with the experimental data on the cross-section energy dependence at a fixed angle of emitted nucleon [13], [14]. It can be seen that the theoretical curve is in satisfactory agreement with the experimental data from the disintegration threshold to a photon energy of 40 MeV. The peak cross-section is represented by different data sets [12], [13], [14] in the range from 80 to 120 μb/sr. The process may be described if only the gauge invariance is preserved strictly and is brought into agreement with the law of conservation of the

four-momentum in the amplitude while applying the requirement of the general covariant scheme. As can be seen in this figure, there is a satisfactory agreement between the theoretical curve and experimental data from the threshold of splitting up to 40 MeV in photon energy.



(a) Photon energy $E_\gamma = 305 \pm 5$ MeV

(b) Photon energy $E_\gamma = 365 \pm 5$ MeV

(c) Photon energy $E_\gamma = 450 \pm 10$ MeV

(d) Photon energy $E_\gamma = 675 \pm 50$ MeV

Figure 3. Angular distributions of differential cross-sections for $^3He(\gamma, p)d$ reaction in the center of mass system for different energies.

By expanding the cross-section with respect to the proton's emission angle at a fixed photon energy, it's possible to trace the evolution of the cross-section's shape as the energy increases. In this work we present theoretical distributions of cross-sections at high photon energies ($E_\gamma = 305 \pm 5$ MeV; 365 ± 5 MeV; 450 ± 10 MeV and 675 ± 50 MeV) and compare them with experimental data from [15]. The calculations are conducted for the two-particle breakup of helium-3 nuclei yield to the angular distributions of cross-sections shown on Figure 3. It can be seen that the proton peak does not disappeared at high energies except the energy $E_\gamma = 675 \pm 50$ MeV. Using the explicit relativistic formulation of the theory [11] removes the question of the role of relativistic corrections and imposes no limitations on its use in various energy regimes and different kinematic conditions. As a result, it provides broad possibilities for conducting research on the structure of non-local fields of matter based on unified requirements.

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REFERENCES

[1] G.E. Brown, A.M. Green, "Three-body forces in nuclear matter," Nuclear Physics A, **137**(1), 1-19 (1969). https://doi.org/10.1016/0375-9474(69)90068-2

[2] G. Derrick, D. Mustard, and J.M. Blatt, "Binding energy of the triton," Phys. Rev. Lett. **6**, 69 (1961). https://doi.org/10.1103/PhysRevLett.6.69

[3] H. Wita, J. Golak, R. Skibiski, K. Topolnicki, and V. Urbanevych, "Investigation of the interaction of circularly and linearly polarized photon beams with a polarized ^{3}He target," Phys. Rev. C, **101**, 2 (2020). https://doi.org/10.1103/PhysRevC.101.024003

[4] R. Schiavilla, V.R. Pandharipande, and R.B. Wiringa, "Momentum distributions in A=3 and 4 nuclei," Nuclear Physics A, (449)(2), 219-242 (1986). https://doi.org/10.1016/0375-9474(86)90003-5.

[5] W.W. Buck, and F. Gross, "Family of relativistic deuteron wave functions," Phys. Rev. D, **20**(9), 2361-2379 (1979). https://doi.org/10.1103/PhysRevD.20.2361.

[6] Lovato, A. and Bombaci, I. and Logoteta, D. and Piarulli, M. and Wiringa, R. B., Benchmark calculations of infinite neutron matter with realistic two- and three-nucleon potentials Phys. Rev. C, **105**, 5 (2022). https://link.aps.org/doi/10.1103/PhysRevC.105.055808

[7] I.E. Lagaris, V.R. Pandharipande, "Phenomenological two-nucleon interaction operator," Nuclear Physics A, **359**, 331-348 (1981). https://doi.org/10.1016/0375-9474(81)90240-2

[8] Y.A. Kasatkin, V.P. Klepikov, P.E. Kuznietsov, "Two-particle photodisintegration of the 3He and 3H nuclei in a relativistic approach with a strictly conserved EM current," Phys. Part. Nuclei Lett. **12**, 481–493 (2015). https://doi.org/10.1134/S1547477115040172

[9] G. Laskaris, W. Ji, et al.,"First measurement of the asymmetry and the Gerasimov-Drell-Hearn integrand from the $^3He(\gamma,p)^2H$ reaction at an incident photon energy of 29 MeV," Phys. Rev. C, **103**, 3 (2021). https://doi.org/10.1103/PhysRevC.103.034311

[10] Yu.A. Kasatkin, V.F. Klepikov, and P.E. Kuznietsov, "Two-particle photodisintegration of light nuclei with conserved EM current," Problems of Atomic Science and Technology, 93(5), 18–25 (2014). https://vant.kipt.kharkov.ua/ARTICLE/VANT_2014_5/article_2014_5_18.pdf

[11] P.E. Kuznietsov, "Unified Description of Photo and Electro Processes on Light Nuclei in Covariant Approach with Exactly Conserved EM Current," East European Journal of Physics, 2(1), 88-92 (2015). https://doi.org/10.26565/2312-4334-2015-1-13

[12] W. Schadow, O. Nohadani, and W. Sandhas, "Photonuclear reactions of three-nucleon systems," Phys. Rev. C, **63**, 044006 (2000). https://doi.org/10.1103/PhysRevC.63.044006.

[13] M. Karlsson, et al. "Measurement of the differential cross section for the two-body photodisintegration of ^{3}He at $\theta^{\rm LAB} = 90^\circ$ using tagged photons in the energy range $14 - 31$ MeV," Phys. Rev. C, **80**, 4 (2009). https://doi.org/10.1103/PhysRevC.80.044001

[14] J.R. Stewart, R.C. Morrison, and J.S. O'Connell, "Photodisintegration of He^3," Phys. Rev. **138**, 2B (1965). https://doi.org/10.1103/PhysRev.138.B372

[15] V. Isbert, G. Audit, N. d'Hose, et al., "Two body photodisintegration of 3He between 200 and 800 MeV / // Nucl. Phys. A, **578**, 525-541 (1994). https://doi.org/10.1016/0375-9474(94)90759-5.

[16] J. Golak, H. Witała, R. Skibiński, K. Topolnicki, Y. Volkotrub, A. Grassi, V. Soloviov, V. Urbanevych, "Theoretical investigations of three-nucleon systems," Acta Physica Polonica. B, Proceedings Supplement, **13**(4), 609–618 (2020). https://doi.org/10.5506/APhysPolBSupp.13.609

АМПЛІТУДИ ДВОЧАСТИНКОВОГО ФОТО РОЗЩЕПЛЕННЯ ЯДЕР ^{3}H, ^{3}He В НЕЛОКАЛЬНОМУ КЕД ПІДХОДІ

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Трьохнуклонні системи відіграють важливу роль у вивченні багаточастинкових сил в ядерній фізиці. Обґрунтована параметризація їх вершинних функцій з подальшим застосуванням для обчислення перерізів реакцій в нелокальному КЕД підході дає основу для дослідження широкого спектру багаточастинкових систем. У даній статті ми проводимо параметризацію амплітуд двохчастинкового фото-розпаду тринуклонних систем (^{3}H, ^{3}He). Ми надаємо загальний опис конструкції хвильової функції для систем з трьома нуклонами, а також параметризацію її вершинних функцій з урахуванням двох- та трьохнуклонних взаємодій на основі формалізму обміну мезонами. У наших обчисленнях ми враховуємо взаємодії за рахунок одно піонного обміну у першому та другому порядках та терм, пов'язаний з обміном ω та ρ мезонами. Потенціал трьохнуклонної взаємодії розраховано як суму потенціалу притяжіння (за рахунок обміну двома піонами) та відповідної частини, яка відповідає за відштовхування. На основі варіаційних амплітуд "Urbana + Model VII"отримано результати для енергетичної залежності диференціального перерізу реакції $^3He(\gamma,p)d$ при куті протону $\theta = 90^\circ$ від порогу до $E_\gamma = 60$ МеВ. Теоретичні передбачення порівняно з наявними експериментальними даними. Також проведено дослідження для кутових розподілів перерізів при високих енергіях фотонів ($E_\gamma = 305 \pm 5$ МеВ; 365 ± 5 МеВ; 450 ± 10 МеВ та 675 ± 50 МеВ). Коректний опис процесів фото-розщеплення ^{3}H, ^{3}He в єдиному підході на основі каліброваної природи електромагнітного поля передбачає застосування цього підходу для інших багаточастинкових систем.

Ключові слова: *тринуклонна система; фоторозпад; переріз; амплітуда; багаточастинкова сила; мезон-обмінний струм*