International Journal of Advanced Research in Physical Science (IJARPS)
Volume 5, Issue 4, 2018, PP 5-9
ISSN No. (Online) 2349-7882
www.arcjournals.org

Analytical Forms of the Deuteron Wave Function for Argonne V18 Potential and the Asymmetry for Polarization Characteristics of the Deuteron

V. I. Zhaba

Uzhgorod National University, Department of Theoretical Physics, 54, Voloshyna St., Uzhgorod, Ukraine.

Corresponding Author:** ***V. I. Zhaba, *Uzhgorod National University, Department of Theoretical Physics, 54, Voloshyna St., Uzhgorod, Ukraine.*

Abstract: *On the received coefficients of the analytical forms for deuteron wave function in coordinate space for the nucleon-nucleon potential Argonne v18 are calculated values of the vector t_{1i} and tensor t_{2j} deuteron polarizations. The angular asymmetry is calculated in the range of momentums 0-7 fm^{-1}, and for momentum asymmetry for deuteron polarizations is obtained for angles 0-180^0.*

Keywords: *deuteron, wave function, analytical forms, asymmetry, vector polarizations, tensor polarizations.*

1. Introduction

Wave function describes the quantum-mechanical system as a whole and is one of the main characteristics of microscopic objects. Knowledge of the form and behavior of the deuteron wave function (DWF) allows us to obtain maximum amount of information about the coupled system of neutron-proton and to theoretically calculate and predict the characteristics that in turn are investigated in the experiment. DWF is written in the form of the sum of the wave functions of the $^3S_1$- and $^3D_1$- states [1], and its radial wave functions *u(r)* and *w(r)* are obtained as solutions to the system of coupled Schrödinger equations [2].

In the review [3] the experimental data of the static parameters of deuteron are systematized, as well as the theoretical values obtained by DWF for various nucleon-nucleon potential models, and a review of the analytical forms of DWF in the coordinate representation has been carried out. Also, there are indicated both analytical forms and parameterization of DWF, necessary for further calculations of theoretical values of the characteristics of processes with the participation of deuteron. It was noted that in a convenient form, DWF are necessary for calculating the static and polarization characteristics of deuteron, as well as for evaluating theoretical values of spin observables for dp- scattering and (d,d')- reactions [4].

In this paper, analytical forms of DWF have been used for theoretical calculations of a set of tensor t_{2j} and vector t_{1i} of deuteron polarizations. Realistic phenomenological Argonne v18 potential [5] have been used for numerical calculations.

2. Analytical forms of DWF

Among the large and diverse list of analytical forms of deuteron wave function in the coordinate representation, it is necessary to distinguish parametrization of DWF for the Paris potential [6], and also parameterization of DWF for realistic superdeep local NN potential (Moscow) was written down as elementary gaussian expansions [7].

In the 2000s, fundamentally new analytical DWFs were also proposed in the coordinate space. These include parameters such as Dubovichenko's [8] and Berezhnoy-Korda-Gakh's [9] parameterizations, as well as the analytical form [10] of the DWF for Nijmegen group potentials (NijmI, NijmII and Nijm93) in such a simple form

$$\begin{cases} u(r) = r^{3/2}\sum_{i=1}^{N} A_i \exp(-a_i r^3), \\ w(r) = r\sum_{i=1}^{N} B_i \exp(-b_i r^3). \end{cases} \tag{1}$$

In paper [11], this analytical form was used to approximate the DWF for potentials of Reid93 and Argonne v18. The resulting wave functions for these potentials do not contain excess nodes. Applying this DWF (1) is a feasible theoretical evaluation of the polarization characteristics of the deuteron and, in particular, the deuteron polarizations of t_{ij} [12-14].

3. Asymmetry for Polarization Characteristics of the Deuteron

The values of the vector t_{1i} and tensor t_{2j} deuteron polarizations are determined through deuteron form factors F_i (i is C, Q, M – charge, quadrupole and magnetic) as [12-15]

$$t_{10}(p,\theta_e) = -\sqrt{\frac{2}{3}}\frac{\eta}{S}\sqrt{(1+\eta)\left(1+\eta\sin^2\left(\frac{\theta_e}{2}\right)\right)}F_M^2(p)tg\left(\frac{\theta_e}{2}\right)\sec\left(\frac{\theta_e}{2}\right), \quad (2)$$

$$t_{11}(p,\theta_e) = \frac{2}{\sqrt{3}S}\sqrt{\eta(1+\eta)}F_M(p)\left[F_C(p)+\frac{\eta}{3}F_Q(p)\right]tg\left(\frac{\theta_e}{2}\right), \quad (3)$$

$$t_{20}(p,\theta_e) = -\frac{1}{\sqrt{2}S}\left(\frac{8}{3}\eta F_C(p)F_Q(p)+\frac{8}{9}\eta^2F_Q^2(p)+\frac{1}{3}\eta\left[1+2(1+\eta)tg^2\left(\frac{\theta_e}{2}\right)\right]F_M^2(p)\right), \quad (4)$$

$$t_{21}(p,\theta_e) = \frac{2}{\sqrt{3}S\cos\left(\frac{\theta_e}{2}\right)}\eta\sqrt{\eta+\eta^2\sin^2\left(\frac{\theta_e}{2}\right)}F_M(p)F_Q(p), \quad (5)$$

$$t_{22}(p,\theta_e) = -\frac{1}{2\sqrt{3}S}\eta F_M^2(p), \quad (6)$$

where the factor is determined by the functions of the electric and magnetic structure $A(p)$ and $B(p)$ and the electron scattering angle θ_e. The values of the vector t_{11} and tensor t_{20} deuteron polarizations are determined by the form factors $F_C(p)$, $F_Q(p)$, $F_M(p)$, and the scattering angle θ_e, and t_{21} - $F_Q(p)$, $F_M(p)$ and θ_e. The values of polarizations t_{22} and t_{10} depend only on the form of the factor $F_M(p)$ and on the angle of scattering.

The polarization of reflected deuteron can be measured if the scattering process is analyzed in detail. Differential cross section for the double process of scattering [14, 16]

$$\frac{d\sigma}{d\Omega d\Omega_2} = \left.\frac{d\sigma}{d\Omega d\Omega_2}\right|_0\left[1+\frac{3}{2}ht_{11}A_y\sin\varphi_2+\frac{1}{\sqrt{2}}t_{20}A_{zz}-\frac{2}{\sqrt{3}}t_{21}A_{xz}\cos\varphi_2+\frac{1}{\sqrt{3}}t_{22}(A_{xx}-A_{yy})\cos 2\varphi_2\right], \quad (7)$$

where $h=\pm 1/2$ - the polarization of the incident electron beam; φ_2 - the angle between two scattering planes; A_y and A_{ij} - vector and tensor analyzing powers of secondary scattering; t_{20}, t_{21} and t_{22} are determined by the formulas (2)-(6).

The differential cross section for elastic scattering of a polarized electron beam from a polarized deuteron target is given by an expression in a laboratory system [15, 17]

$$\frac{d\sigma}{d\Omega_e}(h;p_z,p_{zz}) = \Sigma(\theta,\varphi)+h\Delta(\theta,\varphi), \quad (8)$$

where h - the spiral of the incident electron beam; p_z and p_{zz} determine the degree of vector and tensor polarizations of the deuteron target. The direction of the deuteron polarization is determined by the angles θ and φ in the system where the z axis is along the direction of the virtual photon, and the y axis is determined by the vectors of the directions of motion of the input and output electrons. The first part on the right-hand side of formula (8) defines a cross section for an unpolarized electron. The second part on the right-hand side of formula (8) describes a spiral-dependent differential cross section for a polarized electron beam and a polarized deuteron target and contains vector deuteron analyzing powers t_{10} and t_{11}:

The paper [15] presents the results for the tensor polarization t_{20}, which depends on the momentum p and the scattering angle of the electrons θ_e. Asymmetry of t_{20} illustrated in dependence on angle θ_e. It is shown that the asymmetry t_{20} is almost independent of free nucleon form factors and, in particular, of the less-known neutron electric form factor. It was also found that the value of t_{20} depends weakly on the scattering angle to $\theta_e \approx 120^0$, since its value is almost the same in this area. This clearly follows from equation (4), because t_{20} goes to the constant $-1/\sqrt{8}$.

The results of the momentum asymmetry for vector t_{1i} and tensor t_{2j} deuteron polarizations (2)-(6) are presented in Figs. 1 and 2. Calculations were made on the analytical forms (1) of DWF with the coefficients [11] for the nucleon-nucleon Argonne v18 potential. In addition to the momentum asymmetry, there is also an angular asymmetry for vector t_{1i} and tensor t_{2j} deuteron polarizations (Figs. 3 and 4).

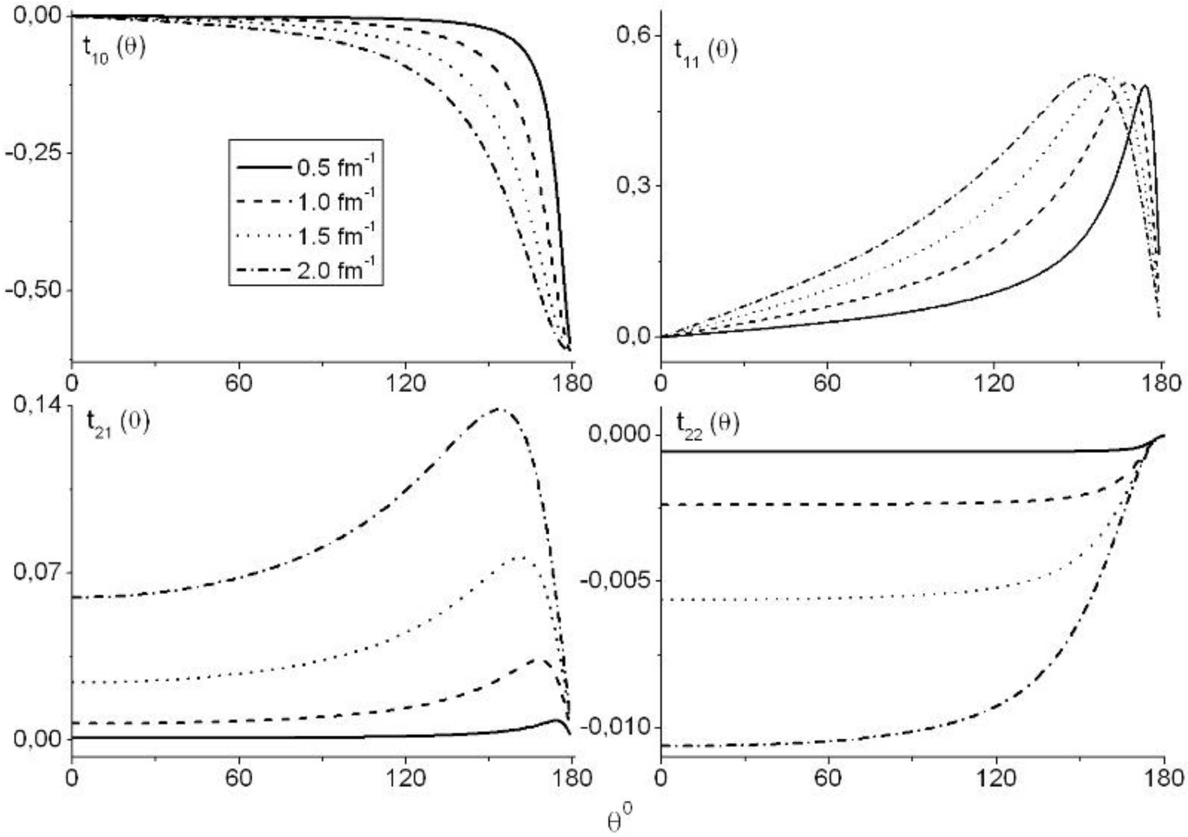

Fig1. *Momentum asymmetry of polarizations* $t_{10}, t_{11}, t_{21}, t_{22}$

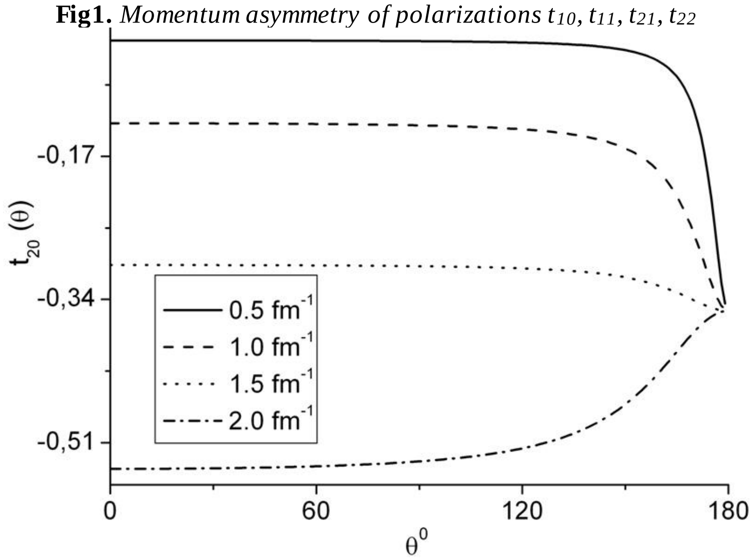

Fig2. *Momentum asymmetry of tensor polarization* t_{20}

Results of similar calculations of asymmetry for vector t_{1i} and tensor t_{2j} deuteron polarizations for Reid93 potentials are quoted in paper [18], where also in the framework of the method of invariant amplitude, the spin observed is observables in backward elastic dp- scattering (the tensor analyzing powers T_{20} and the polarization transmission κ_0); in the wide range of momentum and scattering angles θ, the momentum asymmetry of the tensor analyzing powers T_{20} and T_{22} is described, which characterize the photoproduction of a negative π- meson in the reaction $\gamma(d,\pi^{-})pp$. In paper [18] the symmetry of T_{20} and T_{22} relative to angle 90^0 is observed, and the ratio R for vector P_x and tensor P_{xz} polarizations is characterized by angular asymmetry.

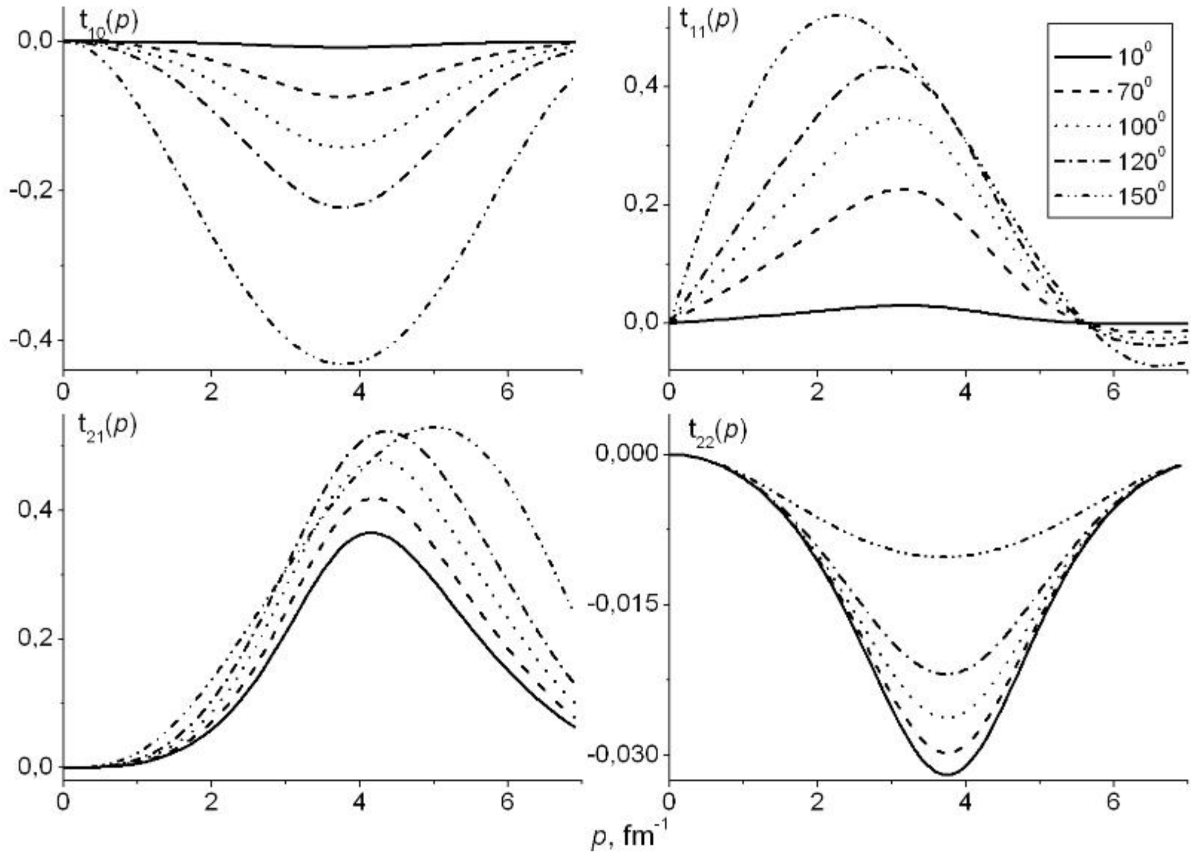

Fig3. *Angular asymmetry of polarizations* $t_{10}, t_{11}, t_{21}, t_{22}$

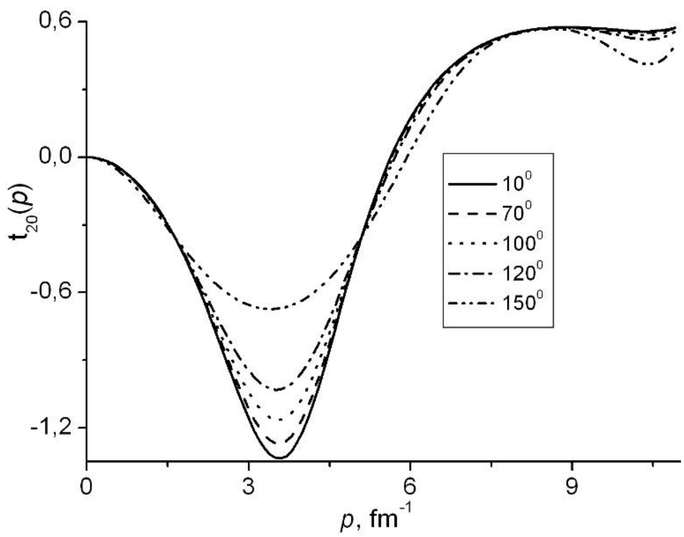

Fig4. *Angular asymmetry of tensor polarization* t_{20}

It is possible to investigate the influence of DWF approximation in the coordinate representation on the subsequent results of calculations of tensor polarization t_{20}. Such a study was made in [18] for values of t_{20} at an angle $\theta=70^0$ if four different DWF approximations were used for the same nucleon-nucleon Reid93 potential. When comparing [19] with the theoretical values of t_{20} with experimental data of conducting collaborations and reviews, there is a good agreement for the range of momentum values p=1-4 fm^{-1}. Due to the lack of experimental data for the deuteron polarizations t_{21}, t_{22}, t_{10} and t_{11} in a wider range of momentum values, the actual and theoretical acquisition of these quantities is relevant.

4. CONCLUSIONS

In addition to the "A_y puzzle", theoretical and experimental studies of other polarization characteristics for processes involving deuteron, for which both angular and momentum asymmetries are available, remain relevant [15, 18]. The obtained results for the vector and tensor deuteron polarizations $t_{ij}(p)$ on the basis of DWF for Argonne v18 potential give some information on the electromagnetic structure of the deuteron and the differential cross section of double scattering.

Results for vector and tensor deuteron polarizations (2)-(6) can be applied to calculate values of differential cross section for the double process of scattering (7) [14, 16] and differential cross section for elastic scattering of a polarized electron beam from a polarized deuteron target (8) [15, 17].

REFERENCES

[1] J.M. Blatt,V.F. Weisskopf, *Theoretical nuclear physics* (Wiley, New York, 1958).

[2] I. Haysak and V. Zhaba, On the nods of the deuteron wave function, Visnyk Lviv Univ. Ser. Phys. 44, 8 (2009).

[3] V.I. Zhaba, Deuteron: properties and analytical forms of wave function in coordinate space, arXiv:nucl-th/1706.08306

[4] V.P. Ladygin et al., Tensor Ayy and Vector Ay Analyzing Powers in the 1H(d,d')X and 12C(d,d')X Reactions at Initial Deuteron Momenta of 9 GeV/c in the Region of Baryonic Resonance Excitation, Phys. Atom. Nucl. 69, 852 (2006).

[5] R.B. Wiringa et al., Accurate nucleon-nucleon potential with charge-independence breaking, Phys. Rev. C 51, 38 (1995).

[6] M. Lacombe et al., Parametrization of the deuteron wave function of the Paris N-N potential, Phys. Lett. B 101, 139 (1981).

[7] V.M. Krasnopol'sky et al., The deuteron structure and NN- phase shifts for realistic local superdeep NN-potential with an extra state, Phys. Lett. B 165, 7 (1985).

[8] S.B. Dubovichenko, Deuteron Form Factors for the Nijmegen Potentials, Phys. Atom. Nucl. 63, 734 (2000).

[9] Yu.A. Berezhnoy et al., Deuteron Form Matter-Density Distribution in Deuteron and Diffraction Deuteron-Nucleus Interaction, Intern. Jour. Mod. Phys. E 14, 1073 (2005).

[10] V.I. Zhaba, New analytical forms of a deuteron wave function for potentials Nijmegen groups, Nucl. Phys. Atom. Energy 17, 22 (2016).

[11] V.I. Zhaba, New analytical forms of wave function in coordinate space and tensor polarization of deuteron, Mod. Phys. Lett. A 31, 1650139 (2016).

[12] R.G. Arnold, C.E. Carlson and F. Gross, Polarization transfer in elastic electron scattering from nucleons anti deuterons, Phys. Rev. C. 23, 363 (1981).

[13] D. Abbott et al., Measurement of Tensor Polarization in Elastic Electron-Deuteron Scattering at Large Momentum Transfer, Phys. Rev. Lett. 84, 5053 (2000).

[14] R. Gilman and F. Gross, Electromagnetic structure of the deuteron, J. Phys. G. 28, R37 (2002).

[15] E.M. Darwish, M.Y. Hussein and B. Abu Sal, Polarization Observables in Elastic Electron-Deuteron Scattering, Appl. Math. & Inform. Sci. 3, 309 (2009).

[16] R.G. Arnold, C.E. Carlson and F. Gross, Elastic electron-deuteron scattering at high energy, Phys. Rev. C. 21, 1426 (1980).

[17] T.W. Donnelly and A.S. Raskin, Considerations of Polarization in Inclusive Electron Scattering from Nuclei, Ann. Phys. (N. Y.) 169, 247 (1986).

[18] V.I. Zhaba, Analytical forms of the wave function and the asymmetry for polarization characteristics of the deuteron, J. Phys. Stud. 21, 4101 (2017).

[19] V.I. Zhaba, Parameterization of the Deuteron form Factors and the Tensor Polarizations, International Journal of Advanced Research in Physical Science 4, 12 (2017).

Citation: *V. I. Zhaba, " Analytical Forms of the Deuteron Wave Function for Argonne V18 Potential and the Asymmetry for Polarization Characteristics of the Deuteron ", International Journal of Advanced Research in Physical Science, vol. 5, no. 4, p. 5-9, 2018.*