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The vector and tensor asymmetries and deuteron wave function for different nucleon-nucleon potentials

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ABSTRACT

Within the framework of the study of radiative corrections to the polarization observed in elastic ed- scattering in leptonic variables have been calculated the Born values of vector A_B^L , A_B^T and tensor A_B^{LL} , A_B^{TT} , A_B^{LT} asymmetries. The deuteron wave functions in coordinate representation for eight nucleon-nucleon potentials (Nijm1, Nijm2, Nijm93, Reid93, Argonne v18, OBEP, MT and Paris) have been used for numerical calculations of vector and tensor asymmetries. The angular-momentum dependence of values vector $A_B^i(p, \theta)$ and tensor $A_B^{ij}(p, \theta)$ asymmetries have been also evaluated in 3D format for Reid93 potentials.

Keywords: deuteron, wave function, vector and tensor asymmetries, longitudinal and transverse polarization, radiative corrections

1. INTRODUCTION

Deuteron can be used as a target for an electron beam or a particle that is scattered on protons and nuclei. For example, in [1] the results for spin-dependent scattering of electrons on polarized protons and deuterons for the BLAST experiment conducted in MIT-Bates are given.

On the electron-positron storage VEPP-3 [2] obtained the results of measuring the components of the analyzing powers T_{2i} in the photodisintegration reaction of a tensor-polarized deuteron.

The spin observed in dp- scattering and the T-invariance test in the application of the modified Glauber theory was investigated in paper [3]. A complete set of deuteron analyzing powers in an elastic dp- scattering at 190 MeV/nucleon is indicated in [4]. The proton and deuteron analyzing powers and 10 spin correlation coefficients were measured in [5] for elastic p+d scattering with the energy of bombarding protons 135 and 200 MeV. The polarization observables for ${}^2\text{H}(d,p)$ ${}^3\text{H}$ and ${}^2\text{H}(d,n)$ ${}^3\text{He}$ reactions for five potentials and their comparison with experimental data's are discussed in [6].

In [7] the angular dependence of the tensor A_{yy} and the vector A_y analyzing powers in inelastic (d,d')- scattering of deuterons with a momentum at 9.0 GeV/c on hydrogen and carbon is measured. Further research and prospects for the process (d,d') are analyzed in [8].

For the theoretical study of the mechanisms and characteristics for these processes with the participation of a deuteron, it is necessary to know exactly the deuteron wave function in the coordinate or momentum representation, as well as the deuteron form-factors.

In the last detailed review [9], the static parameters of deuteron obtained from DWF for different nucleon-nucleon potentials and models are systematized, as well as an overview, list and characteristics for analytic forms of DWF in the coordinate representation are given.

In this paper we use the analytic forms of DWF for theoretical calculations of a set of tensor and vector asymmetries. Nucleon-nucleon realistic phenomenological potentials of Nijmegen group (NijmI, NijmII, Nijm93, Reid93) and Argonne group (Argonne v18) as well as other widely used and popular potentials (OBEP, MT, Paris) are used for numerical calculations.

2. DWF IN COORDINATE REPRESENTATION

Among the various numbers of DWF parameterization forms in the coordinate representation, one can distinguish the following:

1) the parameterization, which was applied to Paris potential [10]:

$$\begin{cases} u(r) = \sum_{j=1}^N C_j \exp(-m_j r), \\ w(r) = \sum_{j=1}^N D_j \exp(-m_j r) \left[1 + \frac{3}{m_j r} + \frac{3}{(m_j r)^2} \right]; \end{cases} \quad (1)$$

where $m_j = \beta + (j-1)m_0$; $\beta = \sqrt{ME_d}$, $m_0 = 0.9 \text{ fm}^{-1}$; M – nucleon mass; E_d – binding energy of the deuteron;

2) the parameterization for Moscow potential [11]:

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

3) the analytical form for Nijmegen group potentials (NijmI, NijmII and Nijm93) [12]:

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

In this paper we use the DWF in the form (3) for the potentials of the Nijmegen group (NijmI, NijmII, Nijm93, Reid93) and the Argonne group (Argonne v18). The coefficients of DWF for these potentials are given in [12, 13].

The search for coefficients of the analytical form (1) was made for the Bonn (OBEP) potential [14] and MT model [15].

3. THE VECTOR A_B^L , A_B^T AND TENSOR A_B^{LL} , A_B^{TT} , A_B^{LT} ASYMMETRIES

In recent years, the problem of the study of leptonic radiative corrections to elastic deuteron-electron scattering remains an urgent issue [16].

To get the radiative corrections to the polarization observables for the reaction $e^-(k_1) + d(p_1) \rightarrow e^-(k_2) + d(p_2)$, it is necessary to parameterize the polarization state of the target in terms of the 4-momenta of particles in this reaction [17]. The polarization state of the target describes the deuteron polarization 4-vector s_μ and the quadrupole polarization tensor $p_{\mu\nu}$. Such a parameterization for the polarization state depends on the directions in which the longitudinal and transverse components of the deuteron polarization in rest frame are determined. The value s_μ describing the deuteron vector polarization.

The longitudinal $s^{(L)}$ and transverse $s^{(T)}$ polarization 4-vectors are defined as [17]

$$s_\mu^{(T)} = \frac{(4\tau + \rho)k_{1\mu} - (1 + 2\tau)q_\mu - (2 - \rho)p_{1\mu}}{\sqrt{Vc(4\tau + \rho)}};$$

$$s_\mu^{(L)} = \frac{2\tau q_\mu - \rho p_{1\mu}}{M_D \sqrt{\rho(4\tau + \rho)}}.$$

Five Born values of vector A_B^L , A_B^T and tensor A_B^{LL} , A_B^{TT} , A_B^{LT} asymmetries were considered For the research problem and the search for «radiative corrections to polarization observables in elastic electron-deuteron scattering in leptonic variables» [17].

The spin-dependent parts of the cross-section is determined by the vector polarization of the initial deuteron and longitudinal polarization of the electron beam [17, 18]

$$\frac{d\sigma_B^L}{dp^2} = -\frac{\pi\alpha^2}{4\tau V^2} \frac{2-\rho}{\rho} \sqrt{\rho(4\tau+\rho)} G_M^2;$$

$$\frac{d\sigma_B^T}{dp^2} = -\frac{\pi\alpha^2}{Vp^2} \sqrt{\frac{(4\tau+\rho)c}{\tau}} G_M G;$$

where

$$G = 2G_C + \frac{2}{3}\eta G_Q; \quad c = 1 - \rho - \rho\tau; \quad \eta = \frac{P^2}{4M_D^2}; \quad \rho = \frac{p^2}{V}; \quad \tau = \frac{M_D^2}{V}.$$

In the laboratory system these expressions for cross-section lead to the values of asymmetries (or the spin correlation coefficients) in the elastic electron-deuteron scattering in the Born approximation [18]

$$\frac{d\sigma_B^L}{dp^2} = \frac{\pi}{\varepsilon_2^2} \eta \sigma_{NS} \sqrt{(1+\eta) \left(1 + \eta \sin^2\left(\frac{\theta_e}{2}\right)\right)} \operatorname{tg}\left(\frac{\theta_e}{2}\right) \operatorname{sec}\left(\frac{\theta_e}{2}\right) G_M^2; \quad (4)$$

$$\frac{d\sigma_B^T}{dp^2} = 2 \frac{\pi}{\varepsilon_2^2} \sigma_{NS} \sqrt{\eta(1+\eta)} \operatorname{tg}\left(\frac{\theta_e}{2}\right) G_M \left(G_C + \frac{\eta}{3} G_Q\right); \quad (5)$$

where ε_2 are the scattered electron energy; $G_C(p)$, $G_Q(p)$, $G_M(p)$ are deuteron form factors; θ_e – the scattering angle of electron.

These asymmetries are formed thanks to the vector polarization of the deuteron target (according to the longitudinal and transverse direction of the spin 4-vectors) and the longitudinal polarization of the electron beam [17]

$$A_B^L = -\eta \sqrt{(1+\eta) \left(1 + \eta \sin^2\left(\frac{\theta_e}{2}\right)\right)} \operatorname{tg}\left(\frac{\theta_e}{2}\right) \operatorname{sec}\left(\frac{\theta_e}{2}\right) G_M^2 I_0^{-1}; \quad (6)$$

$$A_B^T = -2\sqrt{\eta(1+\eta)} \operatorname{tg}\left(\frac{\theta_e}{2}\right) G_M \left(G_C + \frac{\eta}{3} G_Q\right) I_0^{-1}; \quad (7)$$

where

$$I_0 = A + B \operatorname{tg}^2\left(\frac{\theta_e}{2}\right).$$

The ratio of the vector longitudinal and transverse polarization asymmetries to the transverse can be written as [18]

$$\frac{A_B^L}{A_B^T} = \frac{d\sigma_B^L / d\sigma_B}{d\sigma_B^T / d\sigma_B} = \frac{2-\rho}{4} \sqrt{\frac{\rho}{c\tau}} \frac{G_M}{G} \quad (8)$$

or in the laboratory system [17]

$$\frac{A_B^L}{A_B^T} = \sqrt{\eta \left(1 + \eta \sin^2 \left(\frac{\theta_e}{2} \right) \right)} \sec \left(\frac{\theta_e}{2} \right) \frac{G_M}{G}. \quad (9)$$

Four-vectors for tensor polarized deuteron target written as

$$s_\mu^{(I)} = \frac{2\varepsilon_{\mu\lambda\rho\sigma} p_{1\lambda} k_{1\rho} k_{2\sigma}}{V\sqrt{Vc\rho}} \text{ at } I=L,T,N.$$

The part of the cross-section in the Born approximation depends on the tensor polarization of the deuteron target [17, 18]

$$\frac{d\sigma_B^p}{dp^2} = \frac{d\sigma_B^{LL}}{dp^2} R_{LL} + \frac{d\sigma_B^{TT}}{dp^2} (R_{TT} - R_{NN}) + \frac{d\sigma_B^{LT}}{dp^2} R_{LT}, \quad (10)$$

where three components for this cross-section:

$$\frac{d\sigma_B^{LL}}{dp^2} = \frac{\pi\alpha^2}{p^4} 2c\eta \left\{ 8G_c G_Q + \frac{8}{3}\eta G_Q^2 + \frac{2c + 4\tau\rho + \rho^2}{2c} G_M^2 \right\}; \quad (11)$$

$$\frac{d\sigma_B^{TT}}{dp^2} = \frac{\pi\alpha^2}{p^4} 2c\eta G_M^2; \quad (12)$$

$$\frac{d\sigma_B^{LT}}{dp^2} = -\frac{\pi\alpha^2}{p^4} 4\eta(2-\rho) \sqrt{\frac{c\rho}{\tau}} G_Q G_M. \quad (13)$$

In the laboratory system these parts lead to the following three asymmetries (or analyzing powers) in the elastic electron-deuteron scattering, that were induced by tensor polarization of the deuteron target and an unpolarized electron beam [18]

$$\frac{d\sigma_B^p}{dp^2} = \frac{\pi}{\varepsilon_2^2} \sigma_{NS} [S_{LL} R_{LL} + S_{TT} (R_{TT} - R_{NN}) + S_{LT} R_{LT}]$$

or this formula it is represented in [17] as

$$I_0 A_B^p = A_B^{LL} R_{LL} + A_B^{TT} (R_{TT} - R_{NN}) + A_B^{LT} R_{LT},$$

where A_B^{LL} , A_B^{TT} , A_B^{LT} are the tensor polarizations asymmetries:

$$A_B^{LL} = \frac{1}{2} \left\{ 8\eta G_c G_Q + \frac{8}{3} \eta^2 G_Q^2 + \eta \left[1 + 2(1+\eta) \operatorname{tg}^2 \left(\frac{\theta_e}{2} \right) \right] G_M^2 \right\} I_0^{-1}; \quad (14)$$

$$A_B^{TT} = \frac{1}{2} \eta G_M^2 I_0^{-1}; \quad (15)$$

$$A_B^{LT} = -4\eta \sqrt{\eta + \eta^2 \sin^2 \left(\frac{\theta_e}{2} \right)} \sec \left(\frac{\theta_e}{2} \right) G_Q G_M I_0^{-1}. \quad (16)$$

Between components there is a following connection $\frac{\pi}{\varepsilon_2^2} \sigma_{NS} S_{ij} = \frac{A_B^{ij}}{I_0}$.

4. CALCULATIONS AND CONCLUSIONS

Figs. 1-5 illustrate the values of vector A_B^L , A_B^T and tensor A_B^{LL} , A_B^{TT} , A_B^{LT} asymmetries (more precisely, it will be an angle dependence or asymmetry for values A_B^i , A_B^j). The calculations were made for Nijm1, Nijm2, Nijm93, Reid93, Argonne v18, OBEPc, MT and Paris potentials. The angular dependence of vector A_B^i and tensor A_B^{ij} asymmetries is clearly expressed and strongly manifested for all these potentials.

The angular-momentum dependence of values vector $A_B^i(p, \theta)$ and tensor $A_B^{ij}(p, \theta)$ asymmetries in 3D format for Reid93 potential are given in Figs. 6 and 7. Here for tensor asymmetries A_B^{LL} and A_B^{TT} there is a hump (peak) at 3.5-4 fm⁻¹ in the range of angles 0-180 degrees. For the tensor asymmetry A_B^{LT} , on the contrary, there is a pit.

The obtained coefficients of vector and tensor asymmetries can be applied for comparison with two sets of components for cross-sections [17]

$$\frac{d\sigma_B^\beta}{dp^2} = V_{\beta A}(-\theta) \frac{d\sigma_B^A}{dp^2} \text{ at } A=L, T \text{ and } \beta=l, t; \quad (17)$$

$$\frac{d\sigma_B^\beta}{dp^2} = T_{\beta A}(-\theta) \frac{d\sigma_B^A}{dp^2} \text{ at } A=LL, TT, LT \text{ and } \beta=ll, tt, lt \quad (18)$$

for polarization four-vectors

$$s_\mu^{(l)} = \frac{2\tau k_{1\mu} - p_{1\mu}}{M_D}; \quad s_\mu^{(n)} = s_\mu^{(N)}; \quad s_\mu^{(t)} = \frac{k_{2\mu} - (1 - \rho - 2\rho\tau)k_{1\mu} - \rho p_{1\mu}}{\sqrt{Vc\rho}}.$$

Moreover, it is of interest to conduct the further study of polarization observables in elastic lepton-deuteron scattering including the lepton mass [19] (and for the case of spin correlation coefficients in the limit of zero lepton mass).

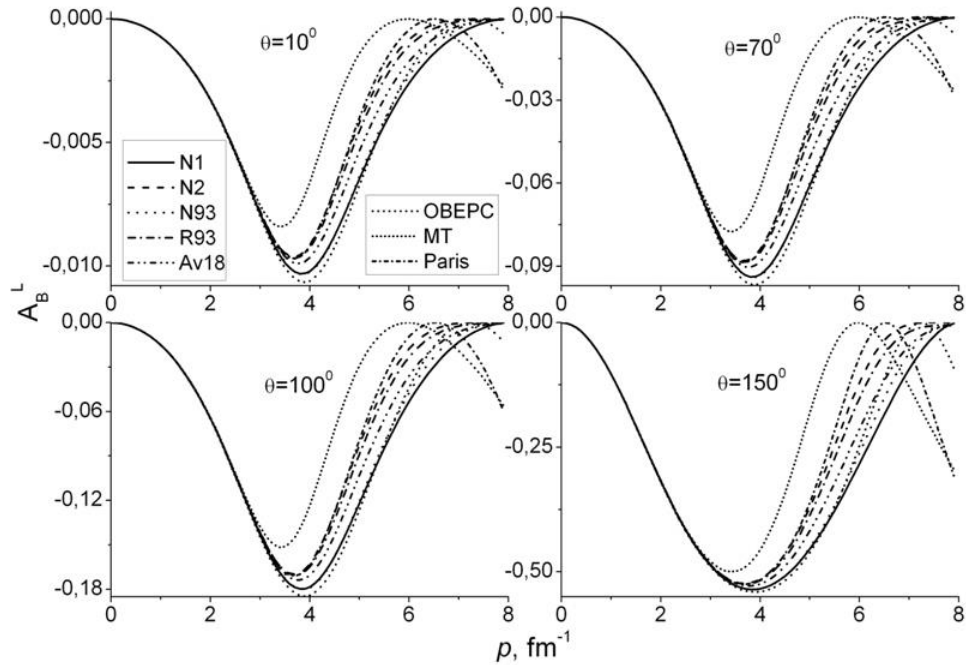


Figure 1. The angular dependence of vector asymmetry A_B^L

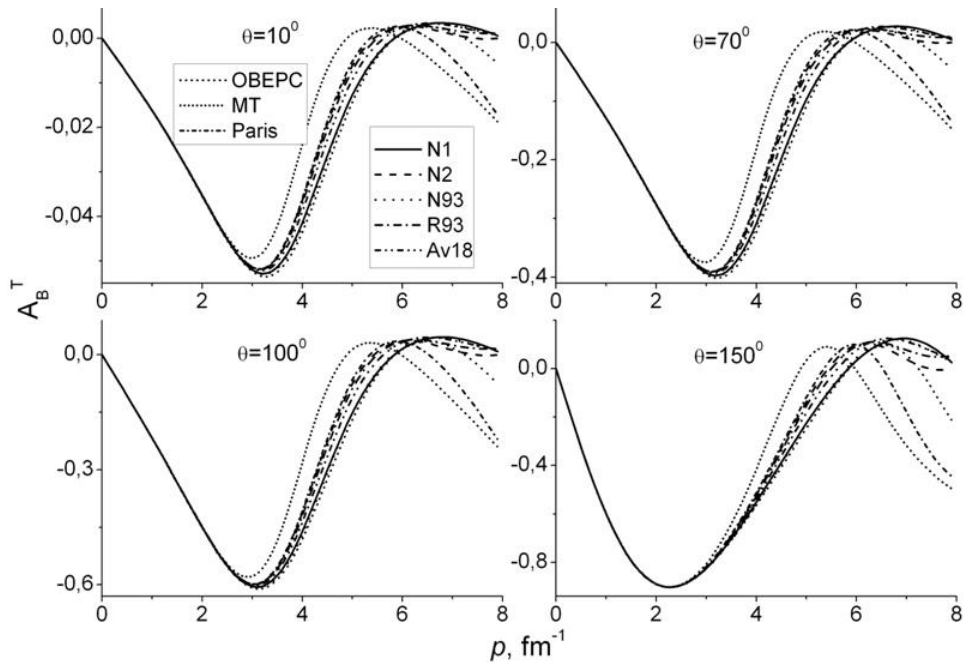


Figure 2. The angular dependence of vector asymmetry A_B^T

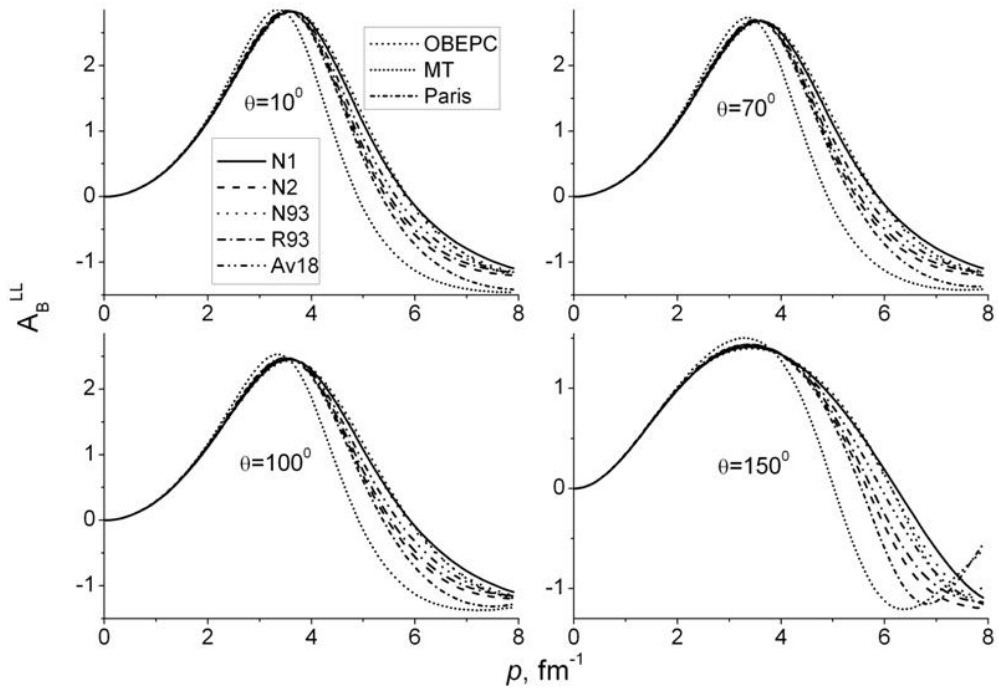


Figure 3. The angular dependence of tensor asymmetry A_B^{LL}

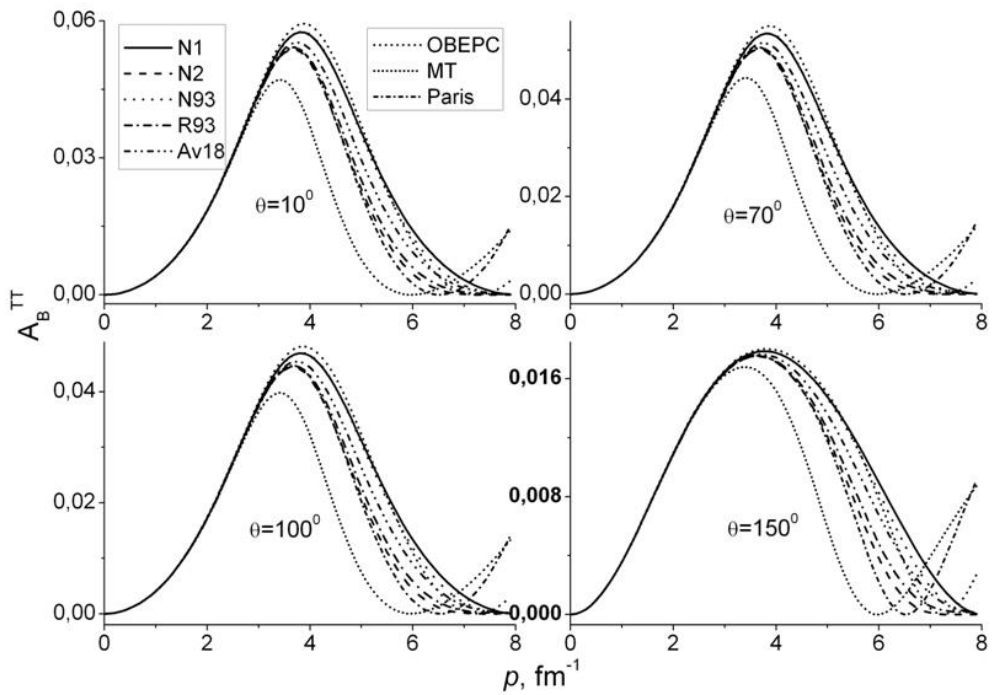


Figure 4. The angular dependence of tensor asymmetry A_B^{TT}

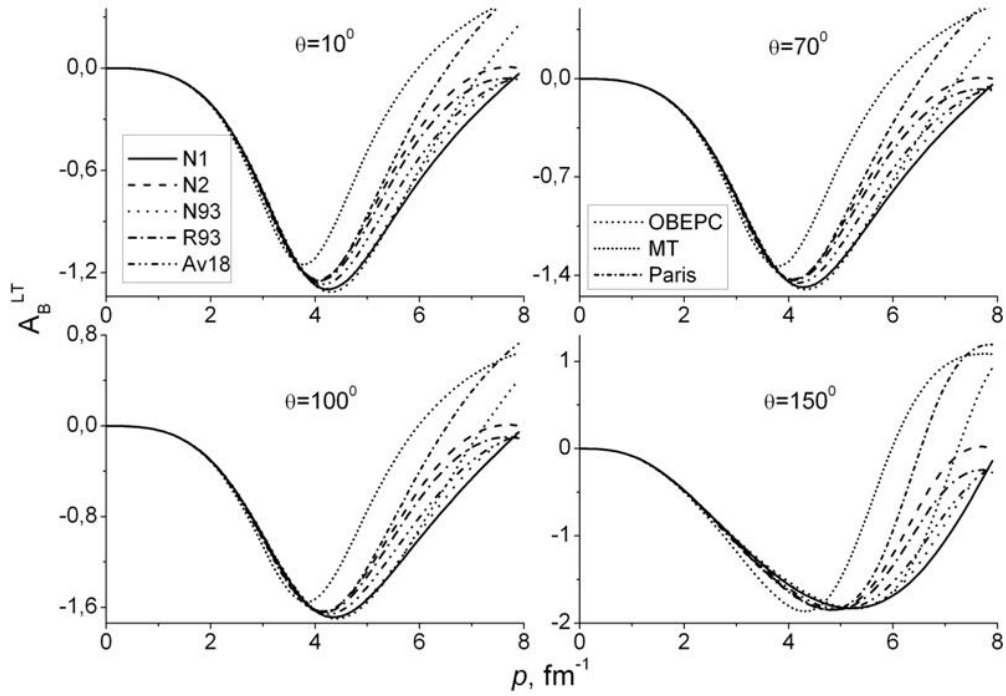


Figure 5. The angular dependence of tensor asymmetry A_B^{LT}

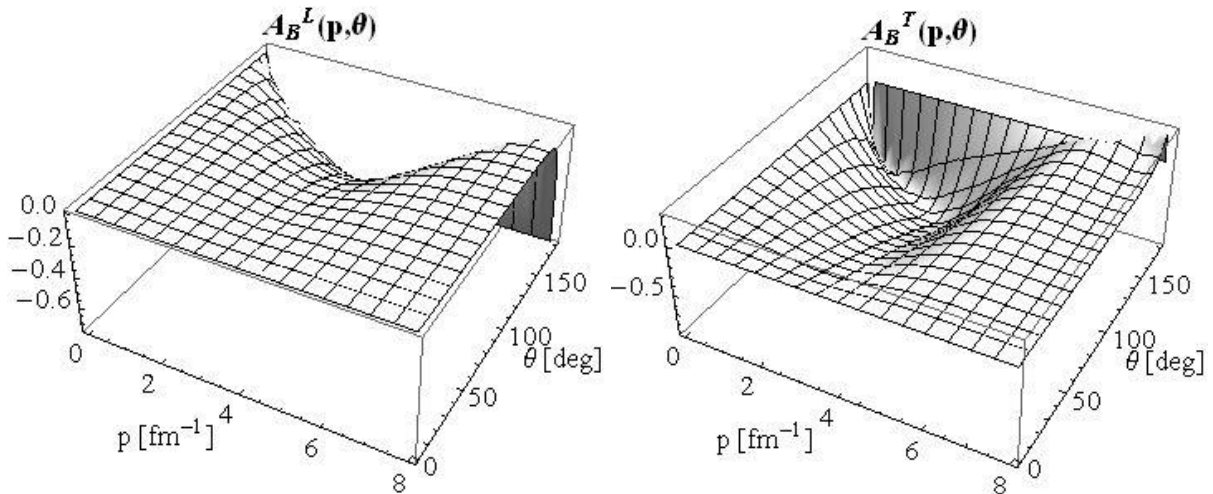


Figure 6. The vector asymmetries A_B^L , A_B^T for Reid93 potential

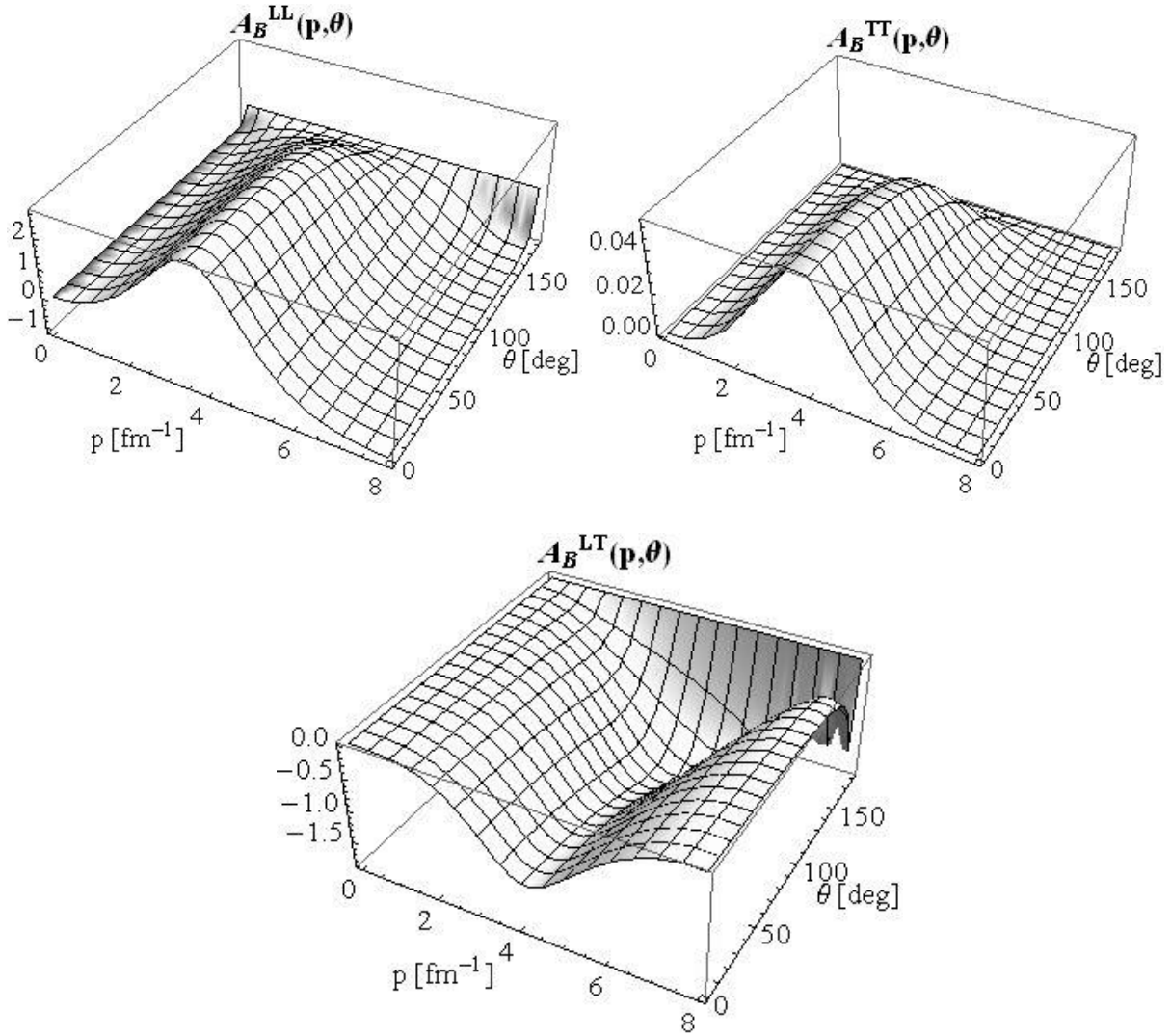


Figure 7. The tensor asymmetries A_B^{LL} , A_B^{TT} , A_B^{LT} for Reid93 potential

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