EFFECT OF THE COULOMB INTERACTION IN A(d,p) FRAGMENTATION

A.P. KOBUSHKIN, YA.D. KRIVENKO-EMETOV[1]

Bogolyubov Institute for Theoretical Physics, Nat. Acad. of Sci. of Ukraine
(14b, Metrolohichna Str., Kyiv 03680, Ukraine),

[1]Institute for Nuclear Research, Nat. Acad. of Sci. of Ukraine
(47, Nauky Prosp., Kyiv 03680, Ukraine)

UDC 539.128.2

In the framework of the Glauber–Sitenko model, we calculate the contribution of the Coulomb interaction in the cross-section of the A(d,p) reaction at high energies and zero angle. It is demonstrated that such an effect significantly increases the differential cross section only at a peak, where the proton momentum p is near half of the deuteron momentum p_d in the lab. frame, $p \sim \frac{1}{2}p_d$. The Coulomb interaction does not change the results in the high-momentum region, where quark effects should be taken into account.

1. Introduction

For several decades, considerable efforts have been done to investigate the deuteron structure in a wide internuclear region, from that where the description is given in terms of nucleons and mesons to that where quarks and gluons should be explicitly used for the description of the deuterons. Reactions with a "hadron probe", due to their high luminosity, play the important role in such studies. Here, we mention only the A(d,p) break-up at zero proton angle [1–12] and the elastic pd-scattering at 180° in the c.m. frame [13–15]. Detailed data on the differential cross section, polarization, tensor analyzing power T_{20}, and polarization transfer κ_0 were obtained for both reactions.

These data show a significant deviation of the observables (cross-section, T_{20}, and κ_0) from the results of theoretical calculations, which cannot be removed by multiple scattering effects without modification of the short-range part of the deuteron wave function [16]. Such a modification comes from the Pauli principle on the level of constituent quarks [17, 18]. As a result, the short-range part of the deuteron wave function includes, apart from the pn component, new components, NN*, N*N and N*N* which cannot be reduced to the pn configuration. Because the main contribution of such states comes from the lowest resonances which have negative parity, the modification generates the effective P-wave in the deuteron which drastically changes the behaviour of the observables in the high-momentum region.

In the framework of such an approach, a good description of all break-up data was obtained [16]. Nevertheless, one important problem was not yet discussed. The data were measured at zero proton angle, $\theta_p = 0$, and the Coulomb interaction might, in principle, give a sizable contribution in the observables. In the present analysis, we take the Coulomb interaction into account by adopting the Akhiezer–Sitenko approach [19][1] to the inclusive ^{12}C(d,p) break-up and find that it significantly increases the cross section only at a peak, where the proton momentum p is near half of the deuteron momentum p_d in the lab. frame, $p \sim \frac{1}{2}p_d$.

The paper is organized as follows. In Sect. 2, we formulate the general formalism. We get the expression for the Coulomb corrected amplitude (Sect. 2.1), give remarks to the strong-interaction part of the amplitude (Sect. 2.2), and obtain the general expression for the invariant differential cross section of the (d,p) break-up at zero proton angle (Sect. 2.3). The procedure of numerical calculations is discussed in Sect. 3. In Sect. 4, we compare our calculations with experiment and give a summary.

2. Formalism

2.1. Coulomb corrected amplitude

We begin from the consideration of a general formalism for a Coulomb correction to the cross-section of the deuteron break-up A(d,p) at the proton longitudinal momentum $p_3 \sim \frac{1}{2}p_d$ and a small transverse momentum $p_\perp$. In this case, it is enough to take the elastic contribution only into account.

[1]For the further applications of this model see, e.g., [20].

Neglecting the Coulomb interaction, the amplitude for the elastic break-up reads

$$F^{\,\rm str}(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp) = \frac{ip_d}{2\pi}\int d^2B e^{i\mathbf{Q}_\perp \mathbf{B}}\times$$

$$\times \int d^3r \psi^*_{\mathbf{k}}(\mathbf{r})\psi_0(\mathbf{r})\left[1 - e^{i\chi_{\rm str}(\mathbf{b}_p,\mathbf{b}_n)}\right] =$$

$$= \frac{ip_d}{2\pi}\int d^2B e^{i\mathbf{Q}_\perp \mathbf{B}}\int d^3r \psi^*_{\mathbf{k}}(\mathbf{r})\psi_0(\mathbf{r})\times$$

$$\times\left[\Gamma_n(\mathbf{b}_n) + \Gamma_p(\mathbf{b}_p) - \Gamma_n(\mathbf{b}_n)\Gamma_p(\mathbf{b}_p)\right] =$$

$$= F_n^{\,\rm str}(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp) + F_p^{\,\rm str}(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp) -$$

$$-F_{np}^{\,\rm str}(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp), \tag{1}$$

where $\psi_0(\mathbf{r})$ and $\psi_{\mathbf{k}}(\mathbf{r})$ are the wave functions of the deuteron and the final proton-neutron system, and $\Gamma_p(\mathbf{b}_p)$ and $\Gamma_n(\mathbf{b}_n)$ are the profile functions for the proton and the neutron; $\mathbf{B} = \frac{1}{2}(\mathbf{b}_p + \mathbf{b}_n)$ and $\mathbf{r}_\perp = \mathbf{b}_p - \mathbf{b}_n$, with $\mathbf{b}_p$ and $\mathbf{b}_n$ being the impact parameters for the proton and the neutron; $\mathbf{p}_d = (0, 0, p_d)$ is the deuteron momentum, $\mathbf{Q}_\perp$ is the momentum transferred to the final proton-neutron system. The definition of the relative momentum between the final proton and the neutron, $\mathbf{k}$, needs a special comment. In the non-relativistic case, it is defined as $\mathbf{k} = (\mathbf{p}_\perp - \frac{1}{2}\mathbf{Q}_\perp, p_3)$. For a relativistic deuteron, $p_d \gg m_d$, we define it by boosting along the z axis to a frame, where the total longitudinal momentum of the two-nucleon system is zero,

$$p_3^* + n_3^* = 0, \qquad \mathbf{p}^*_\perp = \mathbf{p}_\perp, \qquad \mathbf{n}^*_\perp = \mathbf{n}_\perp, \tag{2}$$

$$k_\perp = \frac{1}{2}(\mathbf{p}_\perp - \mathbf{n}_\perp) = \mathbf{p}_\perp - \frac{1}{2}\mathbf{Q}_\perp,\ k_3 = \frac{1}{2}(p_3^* - n_3^*), \tag{3}$$

where $\mathbf{p}^*$ and $\mathbf{n}^*$ are, respectively, momenta of the final proton and the neutron in the new frame; $\mathbf{p}$ and $\mathbf{n}$ are the same momenta in the lab. frame. Of course, such a definition can be accepted only near the region $p_3 \sim \frac{1}{2}p_d$. Assuming that the transverse motion is non-relativistic, we simply get

$$k_3 = \frac{\sqrt{M^2 + \frac{1}{2}p_d^2}}{E_d}\,\widetilde{p}, \qquad \text{where} \qquad p_3 = \frac{1}{2}p_d + \widetilde{p}. \tag{4}$$

The profile function is given by

$$\Gamma(\mathbf{b}) = \frac{1}{2\pi i p_N}\int d^2l e^{-i\mathbf{l}\mathbf{b}} f_N(q) =$$

$$= \frac{(1 - i\rho_N)\sigma_N}{4\pi\beta_N^2} e^{-\frac{1}{2}b^2/\beta_N^2}, \tag{5}$$

where

$$f_N(l) = \frac{(i + \rho_N)p_N\sigma_N}{4\pi} e^{-\frac{1}{2}\beta_N^2 l^2} \tag{6}$$

with β_N^2 is the slope parameter for the nucleon-nucleus scattering, σ_N is the total cross section, and ρ_N is the ratio of the real to imaginary parts of the amplitude. Later on, we will use a natural approximation $\sigma_p = \sigma_n \equiv \sigma$, $\beta_p = \beta_n \equiv \beta$, and $\rho_N = 0$.

Following the prescription in [21], the Coulomb interaction is included by adding the Coulomb, $\chi_{\rm C}(b_p)$, and screening Coulomb, $\chi_{\rm scr}$, phase shifts to the strong-interaction phase function $\chi_{\rm str}(\mathbf{b}_p, \mathbf{b}_n)$, i.e.

$$\Gamma(\mathbf{b}_p, \mathbf{b}_n) = 1 - e^{i\chi_{\rm str}(\mathbf{b}_p,\mathbf{b}_n)} \to$$

$$\to 1 - e^{i[\chi_{\rm str}(\mathbf{b}_p,\mathbf{b}_n) + \chi_{\rm scr} + \chi_{\rm C}(b_p)]} =$$

$$= \Gamma(\mathbf{b}_p, \mathbf{b}_n) + e^{i\chi_{\rm scr}}\left[e^{-i\chi_{\rm scr}} - e^{i\chi_{\rm C}(b_p)}\right]\times$$

$$\times\left[1 - \Gamma(\mathbf{b}_p, \mathbf{b}_n)\right], \tag{7}$$

where the Coulomb and screening Coulomb phase shifts are given by

$$\chi_{\rm C}(b_p) = \frac{2Z\alpha}{v_p}\ln p_3 + \frac{4\pi Z\alpha}{v_p}\left[\ln b_p\int_0^{b_p} T_c(b')b'db' +\right.$$

$$\left.+\int_{b_p}^{\infty} T_c(b')\ln b' b' db'\right] \equiv \chi_0 + \widetilde{\chi}_{\rm C}(b_p), \tag{8}$$

$$\chi_{\rm scr} = -\frac{2Z\alpha}{v_p}\ln 2p_3 R_{\rm scr}, \tag{9}$$

respectively. Here, $T_c(b) = \int \rho_c(r)dz$ is the thickness function corresponding to the nucleon charge distribution, $\rho_c(r)$, normalized by $\int \rho_c(r)d^3r = 1$; v_p is the proton velocity, $R_{\rm scr}$ is the atomic screening radius, Z is the atomic number, and $\alpha \approx 1/137$ is the fine structure constant.

After that, the Coulomb amplitude reads

$$F^{\rm C}(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp) = e^{i\chi_{\rm scr}} \frac{ip_d}{2\pi} \int d^2B e^{i\mathbf{Q}_\perp \mathbf{B}} \int d^3r \times$$

$$\times \psi^*_{\mathbf{k}}(\mathbf{r})\psi_0(\mathbf{r}) \left\{ \left[e^{-i\chi_{\rm scr}} - e^{i\chi_{\rm c}(b_p)} \right] \right\} \times$$

$$\times (1 - \Gamma_p - \Gamma_n + \Gamma_p\Gamma_n) =$$

$$= F^{\rm C}_{\rm dis} - F_p^{\rm C} - F_n^{\rm C} + F_{pn}^{\rm C}. \quad (10)$$

Now let us consider the contributions of different terms of this expression.

C o u l o m b d i s s o c i a t i o n. One simply gets

$$F^{\rm C}_{\rm dis} = \frac{ip_d}{2\pi} G\left(\tfrac{1}{2}\mathbf{Q}, \mathbf{k}\right) \times$$

$$\times \int d^2b_p e^{i\mathbf{b}_p\mathbf{Q}} \left[e^{-i\chi_{\rm scr}} - e^{i\chi_{\rm c}(b_p)} \right], \quad (11)$$

where

$$G\left(\tfrac{1}{2}\mathbf{Q}, \mathbf{k}\right) = \int d^3r e^{\frac{i}{2}\mathbf{Q}\mathbf{r}} \psi^*_{\mathbf{k}}(\mathbf{r})\psi_0(\mathbf{r}) \quad (12)$$

is the transition form factor. To perform the integration over d^2b_p it is useful to introduce a point charge phase shift [21]

$$\chi_{\rm pt}(b_p) = \frac{2Z\alpha}{v_p} \ln p_3 b_p = \chi_0 + \widetilde{\chi}_{\rm pt}(b_p), \quad (13)$$

where

$$\widetilde{\chi}_{\rm pt}(b_p) = \frac{2Z\alpha}{v_p} \ln b_p,$$

and rewrite identically $\left[e^{-i\chi_{\rm scr}} - e^{i\chi_{\rm c}}\right] = \left[e^{-i\chi_{\rm scr}} - e^{i\chi_{\rm pt}}\right] + \left[e^{i\chi_{\rm pt}} - e^{i\chi_{\rm c}}\right]$. Finally one arrives to

$$F^{\rm C}_{\rm dis} = G\left(\tfrac{1}{2}\mathbf{Q}, \mathbf{k}\right) \left[\mathcal{F}_{\rm pt}(Q) + \Delta\mathcal{F}(Q)\right] \equiv$$

$$\equiv G\left(\tfrac{1}{2}\mathbf{Q}, \mathbf{k}\right) \mathcal{F}_{\rm c}(Q), \quad (14)$$

where

$$\mathcal{F}_{\rm pt}(Q) = -\frac{2Z\alpha p_d}{vQ^2} e^{i\varphi_{\rm c}} \quad (15)$$

is the scattering amplitude on the Coulomb potential of a point charge ($\varphi_{\rm C} = -\frac{2Z\alpha}{v}\left[C + \ln\left(\frac{Q}{2p_3}\right)\right]$, where $C = 0.577215$ is the Euler constant) and

$$\Delta\mathcal{F}(Q) \equiv e^{i\chi_0}\Delta\widetilde{\mathcal{F}}(Q) =$$

$$= ip_d \int_0^\infty db_p b_p J_0(Qb_p) \left[e^{i\chi_{\rm pt}(b_p)} - e^{i\chi_{\rm c}(b_p)} \right], \quad (16)$$

where $J_0(x)$ is the Bessel function.

P r o t o n s c a t t e r i n g a f f e c t e d b y t h e C o u l o m b i n t e r a c t i o n.

$$F_p^{\rm C} = \frac{\sigma}{4\pi} G\left(-\tfrac{1}{2}\mathbf{Q}, \mathbf{k}\right) \mathcal{C}_c(Q), \quad (17)$$

where $\mathcal{C}_c(Q) = \int\limits_0^\infty dq q e^{-\frac{\beta^2}{2}(q^2+Q^2)} I_0(\beta^2 Qq)\mathcal{F}_c(q)$.

N e u t r o n s c a t t e r i n g a f f e c t e d b y t h e C o u l o m b i n t e r a c t i o n.

$$F_n^{\rm C} = \int \frac{d^2l}{2\pi i n} G\left(\tfrac{1}{2}\mathbf{Q} - \mathbf{l}, \mathbf{k}\right) f_n(l)\mathcal{F}_c(|\mathbf{Q}_\perp - \mathbf{l}_\perp|). \quad (18)$$

$n-p$ r e s c a t t e r i n g a f f e c t e d b y t h e C o u l o m b i n t e r a c t i o n.

$$F_{np}^{\rm C} = -\frac{1}{(2\pi)^2 pn} \int d^2l d^2l' G\left(-\tfrac{1}{2}\mathbf{Q} + \mathbf{l}', \mathbf{k}\right) \times$$

$$\times \mathcal{F}_c(|\mathbf{Q} - \mathbf{l} - \mathbf{l}'|) f_p(l) f_n(l'). \quad (19)$$

For the Gaussian amplitudes $f_p(l)$ and $f_n(l')$, one can integrate over the angles

$$F_{np}^{\rm C} = -\left(\frac{\sigma}{4\pi}\right)^2 \int_0^\infty dq \int_0^\infty dq' q q' G\left(\tfrac{1}{2}q', \mathbf{k}\right) \times$$

$$\times \mathcal{F}_c(q) \widetilde{I}_0\left(-\tfrac{1}{2}\beta^2 qq'\right) \widetilde{I}_0\left(\tfrac{1}{2}\beta^2 qQ\right) \times$$

$$\times e^{-\frac{1}{4}\beta^2[(q-q')^2 + (q-Q)^2)}, \quad (20)$$

where $\widetilde{I}_0(x) = e^{-|x|}I_0(x)$. Deriving (20), we used the fact that the form factor $G(\mathbf{Q}', \mathbf{k})$ does not depend on the $\mathbf{Q}$-direction when the vector $\mathbf{k}$ is directed over the z axis. We have also assumed that the nucleon-nuclei amplitudes are the same for the proton and the neutron.

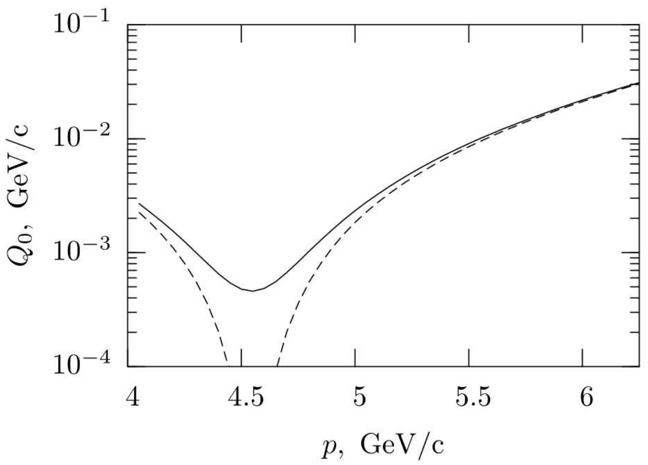

Fig. 1. Dependence of the Q_0 momentum (22) on the proton longitudinal momentum p for the deuteron momentum p_d = 9.1 GeV/c. The solid line is for the experimental masses of the proton and the neutron, and the dashed line is for $m_p = m_n = \frac{1}{2}m_d$

Finally, one gets

$$F(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp) =$$

$$= F^{\rm str} + e^{i\chi_{\rm scr}}\left(F_{\rm dis}^{\rm C} - F_p^{\rm C} - F_n^{\rm C} + F_{np}^{\rm C}\right). \tag{21}$$

As a result of the infinite range of the Coulomb interaction, the amplitude (15) is diverged at $Q \to 0$. Due to the binding energy of the deuteron, the neutron loses a part of its longitudinal momentum Q_0 at the limit when the transverse momentum $Q_\perp \to 0$ [19]. We estimate it to be

$$Q_0 = \frac{m_n^2 + (p_d - p)^2 - (E_d - E_p)^2}{2(p_d - p)}. \tag{22}$$

To take this effect into account, one has to change $Q^2 \to Q^2 + Q_0^2$ in the denominator of amplitude (15). The momentum Q_0 is minimal at $p = \frac{1}{2}p_d$ (see Fig. 1).

2.2. Strong-interaction part of the amplitude

As was mentioned before, the strong-interaction amplitude (1) corresponds to the situation where the deuteron constituents (the proton and the neutron) suffer elastic scattering only. Its square is proportional to the so-called "disintegration cross section". To calculate the inclusive cross section, one has to add two contributions, the disintegration and absorption cross sections [22, 23]. In the latter, the neutron suffers inelastic collisions, but the proton keeps the elastic scattering only. It is the core of the Bertocchi–Treleani model.

In [16], the Bertocchi–Treleani model [23] was modified in the following way:

– the deuteron wave function was considered in the framework of "minimal relativization prescription" with the dynamics in the infinite-momentum frame [24,25];

– it takes into account the Pauli principle at the constituent quark level.

According to the Resonating Group Method (RGM), the Pauli principle at the level of constituent quarks modifies the deuteron wave function at short distances as follows [17, 18]:

$$\psi^d(1, 2, ..., 6) = \widehat{A}\phi_N(1, 2, 3)\phi_N(4, 5, 6)\chi(\mathbf{r}). \tag{23}$$

Here, $\widehat{A}$ is the antisymmetrizer for quarks from different three-quark ($3q$) bags, ϕ_N are nucleon $3q$ clusters, $\chi(\mathbf{r})$ is the RGM distribution function, and $\mathbf{r}$ stands for the relative coordinate between two $3q$ bags. Due to the presence of the antisymmetrizer in (23), the deuteron wave function decomposed into $3q \times 3q$ clusters includes nontrivial NN* components apart from the standard pn component. Most of the isobars N* have negative parity, and thus they generate an effective P-wave in the deuteron.

Following [17, 18], one can choose $\chi(\mathbf{r})$ as a conventional two-nucleon deuteron wave function renormalized by the condition formulated in [26].

2.3. Cross section

The differential cross section is given by

$$\frac{d^3\sigma}{d^3k} = \frac{1}{(2\pi)^3}\int d^2n\,|F(\mathbf{p}_\perp, p_3, \mathbf{Q}_\perp)|^2\,, \tag{24}$$

where $\mathbf{p}$ and $\mathbf{n}$ are the proton and neutron momenta. In the case where $p_\perp = 0$, the transverse momentum $\mathbf{Q} = \mathbf{n}_\perp$, and the integral over the angle becomes trivial. Finally, we arrive at the following expression for the invariant differential cross section:

$$E_p\frac{d^3\sigma}{d^3p} = \frac{E_p^*}{(2\pi)^2}\int\limits_0^\infty dnn\,|F(\mathbf{0}_\perp, p_3, n)|^2\,, \tag{25}$$

where E_p^* is the proton energy in the deuteron rest frame.

Due to the oscillating factor $e^{i\chi_{\rm scr}}$ in (21), the strong-interaction and Coulomb parts of the amplitude do not interfere in (25).

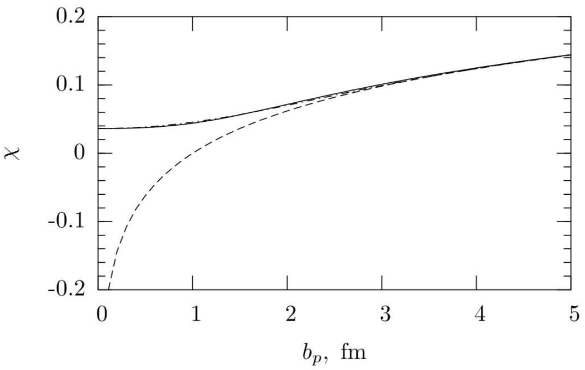

Fig. 2. Coulomb phase shift $\widetilde{\chi}_{\rm C}(b_p)$ (solid line) and the phase shift for a point charge $\widetilde{\chi}_{\rm pt}(b_p)$ (dashed line) for ^{12}C. The dash-dotted line is for the approximation of the phase shift $\widetilde{\chi}_{\rm ap}(b_p)$

3. Numerical Calculations

We use the nuclear charge density which corresponds to the harmonic oscillator well

$$\rho_c(r) = \frac{2}{\pi^{\frac{3}{2}} Z a_0^3}\left[1 + (Z-2)\frac{r^2}{3a_0^2}\right] e^{-r^2/a_0^2}, \qquad (26)$$

where $\langle r^2\rangle = a_0^2\left(\frac{5}{2} - \frac{A}{4}\right)$. For ^{12}C, the parameter $a_0 =$ 1.60 fm [21]. The thickness function

$$T_c(b) = \frac{2}{\pi Z a_0^2}\left[1 + \frac{Z-2}{6} + (Z-2)\frac{b^2}{3a_0^2}\right] e^{-b^2/a_0^2}. \qquad (27)$$

The Coulomb phase shift $\widetilde{\chi}_{\rm C}(b_p)$ is displayed in Fig. 2.

In numerical calculations, we use parametrizations for the phase shift $\widetilde{\chi}_{\rm C}(b)$ (8) and the real and imaginary parts of the potential correction $\Delta\widetilde{\mathcal{F}}_c(Q)$ defined in Eq. (16) which are given in Appendix.

All calculations are done with the deuteron wave function for the Nijm-I potential [27]. The S and D wave components of the wave function were approximated by a sum of Gaussians

$$u(r) = r\sum_{i=1}^{N} A_i e^{-\alpha_i r^2}, \quad w(r) = r^3\sum_{i=1}^{N} B_i e^{-\gamma_i r^2}. \qquad (28)$$

For the Gaussian wave function (28), one cannot construct the wave function for the unbound pn system which fulfils the conditions of orthogonality and completeness. Similarly to [20], we can construct only a function which is orthogonal to the deuteron wave function (28)

$$\psi_{\mathbf{k}}(\mathbf{r}) = e^{i\mathbf{kr}} - (2\pi)^{3/2}\psi_s(r)\phi_s(k)/N_s, \qquad (29)$$

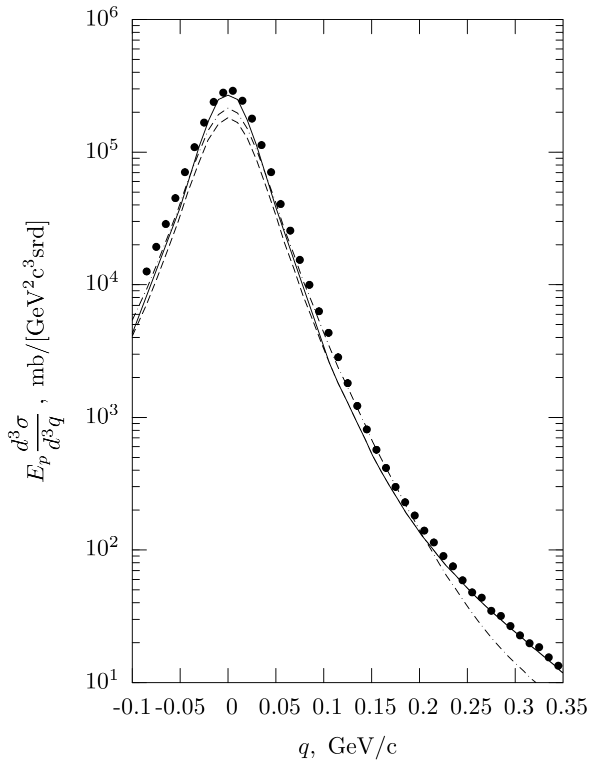

Fig. 3. Invariant cross section of the 0° inclusive ^{12}C(d,p) break-up at p_d = 9.1 GeV/c versus the proton momentum in the deuteron rest frame. The experimental points are from [1, 2]. The dash-dotted curve is for the quasiimpulse approximation (see the text), the dashed curve is for multiple scattering + Pauli principle at the quark level (PQL), the full curve is for the multiple scattering + PQL corrected by the Coulomb interaction

where $\psi_s(r) = \frac{1}{(4\pi)^{1/2}r}u(r)$, N_s is the probability for the S-wave in the deuteron, and $\phi_s(k)$ is the Fourier transform of the deuteron S-wave function,

$$\phi_s(k) = \sqrt{\frac{1}{4\pi}}\sum_{i=1}^{N}\frac{A_i}{(2\alpha_i)^{3/2}}e^{-k^2/(4\alpha_i)}.$$

Finally, we get the following expression for the form factor:

$$G\left(\tfrac{1}{2}\mathbf{Q},\mathbf{k}\right) = (2\pi)^{3/2}\left\{\phi_s\left(\left|\tfrac{1}{2}\mathbf{Q}-\mathbf{k}\right|\right) - \right.$$

$$\left. -\pi^{3/2}\frac{\phi_s(k)}{N_s}\sum_{i,j=1}^{N}\frac{A_iA_j}{(\alpha_i+\alpha_j)^{3/2}}\exp\left[-\frac{Q^2}{16(\alpha_i+\alpha_j)}\right]\right\}. \qquad (30)$$

In numerical calculations, we take the experimental value σ =340 mb for the total p^{12}C cross section. The slope parameter was calculated in the framework of the Glauber–Sitenko model and is $\beta^2 = 69.3$ (GeV/c)^2.

4. Comparison with Experiment and Summary

In Fig. 3, the results of calculations are compared with experimental cross section data. We also compare our results with those in the quasiimpulse approximation, i.e. $\frac{d^3\sigma}{d^3q} \approx \sigma^{\rm in}_{n{\rm C}}|\psi_d(q)|^2$, where q is the proton momentum in the deuteron rest frame, and $\sigma^{\rm in}_{n{\rm C}}$ is the inelastic neutron-carbon cross section[2]. One sees that the Coulomb interaction strongly increases the cross section at the peak near $q \sim 0$ (which corresponds to $p \sim \frac{1}{2}p_d$). Out of the peak, such an effect sharply decreases and becomes negligibly small at $q >$100 MeV/c. So it cannot affect the region, $q >$200 MeV/c, where quark effects are assumed to be significant.

The authors would like to thank E.A. Strokovsky for reading the manuscript and useful comments. This work was supported by a grant of the State Foundation of Fundamental Research of Ukraine F/16-457-2007.

APPENDIX

In numerical calculations, we use the following parametrizations for the phase shift $\widetilde{\chi}_{\rm C}(b)$,

$$\widetilde{\chi}_{\rm ap}(b) = \frac{Z\alpha}{v_p}\ln \quad b^2 + \frac{A_1}{1+A_2b^2} \qquad (31)$$

(where A_1 =2.2416 fm^2, A_2 =0.34 fm^{-2}, and b is defined in fm), and the real and imaginary parts of the potential correction $\Delta\widetilde{\mathcal{F}}_c(Q)$

$$\Re{\rm e}\Delta\widetilde{\mathcal{F}}_c(Q) = -\frac{2Z\alpha p_d}{v}\left[\frac{\cos\varphi_r}{A_r+Q^2} + C_rQe^{-\frac{Q^2}{Q_r^2}}\right], \qquad (32)$$

$$\Im{\rm m}\Delta\widetilde{\mathcal{F}}_c(Q) = -\frac{2Z\alpha p_d}{v}\left[\frac{A_i}{B_i+Q^2} + C_ie^{-\frac{Q^2}{Q_i^2}}\right], \qquad (33)$$

where $\varphi_r = -\frac{2Z\alpha p_d}{v}\left[C + \ln \quad \frac{B_r+Q}{2p_3} \quad\right]$ and $A_r = 0.035$ GeV^2, $B_r = 0.086$ GeV, $C_r = -12.410$ GeV^{-3}, $Q_r^2 = 0.125$ GeV^2, $A_i = 0.264$, $B_i = 0.799$ GeV^2, $Q_i^2 = 0.0242$ GeV^2, $C_i = -1.112$ GeV^{-2}.

1. V.G. Ableev *et al.*, Nucl. Phys. A **393**, 491 (1983); *ibid.* **411–501**, 591 (1984) (E); Pis'ma Zh. Eksp. Teor. Fiz. **37**, 196 (1983); JINR Rap. Commun. **1[54]**, 10 (1992).
2. S.A. Zaporozhets *et al.*, in *Proceedings of VIII International Seminar in High Energy Problems (Dubna, June 1986)* D1,2-86-668 (1986), p. 341.
3. C.F. Perdrisat *et al.*, Phys. Rev. Lett. **59**, 2840 (1987).
4. V.G. Ableev *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **47**, 558 (1988).
5. V. Punjabi *et al.*, Phys. Rev. C **39**, 608 (1989).
6. V.G. Ableev *et al.*, JINR Rap. Commun. **4[43]-90**, 5 (1990).
7. A.A. Nomofilov *et al.*, Phys. Lett. B **325**, 327 (1994).
8. T. Aono *et al.*, Phys. Rev. Lett. **74**, 4997 (1995).
9. L.S. Azgirey *et al.*, Phys. Lett. B **387**, 37 (1996).
10. N.E. Cheung *et al.*, Phys. Lett. B **284**, 210 (1992).
11. T. Dzikowski *et al.*, in *Proceedings of International Seminar in Workshop 'Dubna 97', JINR* E2-92-25 (1992), p. 181.
12. B. Kuehn *et al.*, Phys. Lett. B **334**, 298 (1994); L.S. Azgirey *et al.*, JINR Rap. Commun. **3[77]-96**, 23 (1996).
13. P. Berthet *et al.*, J. Phys. G: Nucl. Phys. **8**, L111 (1982).
14. L.S. Azgirey *et al.*, Phys. Atom. Nucl. **61**, 432 (1998); Phys. Lett. B **391**, 22 (1997).
15. V. Punjabi *et al.*, Phys. Lett. B **350**, 178 (1995).
16. A.P. Kobushkin, Phys. Lett. B **421**, 53 (1998); Phys. Atom. Nucl. **62**, 1400 (1999); A.P. Kobushkin, in *Proceedings of the RCNP-TMU Symposium "Spins in Nuclear and Hadronic Reactions"*, edited by H. Yabu, T. Suzuki, and H. Toki (World Sci., Singapore, 2000), p. 223.
17. L.Ya. Glozman, A.P. Kobushkin, and A.I. Syamtomov, Phys. Atom. Nucl. **59**, 795 (1996).
18. L.Ya. Glozman and E.I. Kuchina, Phys. Rev. C **49**, 1149 (1994).
19. A.I. Akhiezer and A.G. Sitenko, Phys. Rev. **106**, 1236 (1957).
20. M.V. Evlanov, A.D. Polozov, and B.G. Struzhko, Ukr. Fiz. Zh. **25**, 813 (1980).
21. R.J. Glauber and G. Matthiae, Nucl. Phys. B **21**, 135 (1970).
22. L. Bertocchi and A. Tékou, Nuovo Cim. **21** A, 223 (1974).
23. L. Bertocchi and D. Treleani, Nuovo Cim. **36** A, 1 (1976).
24. L.L. Frankfurt and M.I. Strikman, Yad. Fiz. **29**, 490 (1979); Phys. Rep. **76**, 215 (1976).
25. A.P. Kobushkin and L. Vizireva, J. Phys. G: Nucl. Phys. **8**, 893 (1982).
26. M. Oka and K. Yazaki, Prog. Theor. Phys. **66**, 556 (1981).
27. W.G. Stoks, R.A.M. Klomp, C.F.P. Terheggen, and J.J. de Swart, Phys. Rev. C **49**, 2950 (1994).

Received 14.12.07

ЕФЕКТ КУЛОНОВОЇ ВЗАЄМОДІЇ У A(d,p)-ФРАГМЕНТАЦІЇ

О.П. Кобушкін, Я.Д. Кривенко-Еметов

Р е з ю м е

Розраховано внесок кулонової взаємодії у переріз реакції розвалу дейтрона A(d,p) при високих енергіях та нульовому куті реєстрації протона. Розрахунок виконано у рамках моделі багаторазового розсіяння Глаубера–Ситенка. Показано, що кулонова взаємодія суттєво збільшує диференціальний переріз лише в області максимуму виходу протонів при імпульсі, близькому до половини імпульсу протона у лабораторній системі. Цей ефект не змінює результатів розрахунків в області великих імпульсів протона, де очікуються суттєвими кваркові ефекти у дейтроні.

[2] For the meaning of the quasiimpulse approximation see, e.g., [1].