Extraction of the neutron charge form factor from the charge form factor of deuteron

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February 19, 2002

Abstract

We extract the neutron charge form factor from the charge form factor of deuteron obtained from $T_{20}(Q^2)$ data at $0 \leq Q^2 \leq 1.717$ (GeV$^2$). The extraction is based on the relativistic impulse approximation in the instant form of the relativistic Hamiltonian dynamics. Our results (12 new points) are compatible with existing values of the neutron charge form factor of other authors. We propose a fit for the whole set (35 points) taking into account the data for the slope of the form factor at $Q^2 = 0$.

Keywords: Relativistic model; Deuteron; Neutron charge form factor

PACS: 13.40.Gp; 14.20.Dh; 24.10.Jv

The behavior of the neutron charge form factor $G_E^n(Q^2)$, $(Q^2 = -q^2$, $q$ - the momentum transfer) is of great importance for the understanding of the electromagnetic structure of nucleons and nuclei. However, $G_E^n(Q^2)$ is still known rather poorly.

As there are no free neutron targets, $G_E^n(Q^2)$ has to be extracted from the data for composite nuclei, for example deuteron or $^3$He. The direct measurement of great precision ($\sim 1.5\%$) is possible only for the slope $dG_E^n(Q^2)/dQ^2$ at $Q^2 = 0$, as determined by thermal neutron scattering.

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While obtaining the information about the neutron from the scattering data on composite systems one encounters two kinds of difficulties. First, the results depend crucially on the model for \(NN\) interaction \[13, 15, 16\]. Second, there exists a dependence on the relativistic effects, exchange currents, nucleon isobar states, final state interaction in inelastic channels etc. \[4, 12\]. The use of polarized beams and polarized targets in recent experiments diminishes uncertainties due to those effects \[3, 4, 5, 7, 8, 9, 11, 13\].

In the present paper the neutron charge form factor is extracted from the experimental data on the deuteron charge form factor obtained through polarization experiments on elastic \(ed\) scattering \[17, 18, 19\]. In the JLab experiments \[19\] the deuteron charge form factor is obtained up to \(Q^2 = 1.717\) (GeV\(^2\)). In this range of momentum transfer the theoretical description of the polarization tensor \(T_{20}(Q^2)\) depends essentially on the choice of the form of \(NN\) interaction and relativistic approach is required.

Our calculations are based on the method of relativistic Hamiltonian dynamics (RHD) which is widely used in present time. One can find the description of RHD method in the reviews \[20\] and especially the case of the deuteron in the reviews \[21, 22\]. We use our own variant \[23, 24\] of the instant form of RHD. This variant permits to take correctly into account the relativistic effects in the elastic \(ed\) scattering in the relativistic impulse approximation \[23\]. The main point of our approach is the construction of the electromagnetic–current operator for the system of interacting particles. In our approach this operator is Lorentz covariant and satisfies the conservation law.

Let us note that, as far as we know, it is for the first time that the neutron charge form factor is determined from an analysis of the deuteron charge form factor.

In our approach in the relativistic impulse approximation the following equation for the deuteron charge form factor takes place (see \[25\] for details):

\[
G_{C}(Q^2) = G_{CC}(Q^2) \left[ G_{E}^{p}(Q^2) + G_{E}^{n}(Q^2) \right] + G_{CM}(Q^2) \left[ G_{M}^{p}(Q^2) + G_{M}^{n}(Q^2) \right]. \tag{1}
\]

Here \(G_{E, M}^{p, n}\) are charge and magnetic form factors of proton and neutron. The fact that nucleons magnetic form factors enter the Eq. (1) is due to the relativistic effect.

The functions \(G_{CC}, G_{CM}\) in (1) are given by:

\[
G_{CC}(Q^2) = \sum_{l, l'} \int d\sqrt{s}d\sqrt{s'} \varphi^l(s) g^{ll'}_{CC}(s, Q^2, s') \varphi^{l'}(s'), \tag{2}
\]

\[
G_{CM}(Q^2) = \sum_{l, l'} \int d\sqrt{s}d\sqrt{s'} \varphi^l(s) g^{ll'}_{CM}(s, Q^2, s') \varphi^{l'}(s'), \tag{3}
\]

here \(\varphi^l(s)\) is the wave function in the sense of RHD (see \[20, 23, 24\]):

\[
\varphi^l(s) = \sqrt{s} u_l(k) k, \quad k = \frac{1}{2} \sqrt{s - 4 M^2}, \quad \sum_l \int u^2_l(k) k^2 dk = 1, \tag{4}
\]
$M$ is the nucleon mass, $l = 0, 2$ - the nucleon angular momentum in the deuteron, $u_t(k)$ - the wave function for the model $NN$ interaction. The functions $g_{CC}^{ll}$, $g_{CM}^{ll}$ are given by the following equations (5)-(11) (note that the same equations were obtained independently in [20]):

$$g_{CC}^{ll}(s, Q^2, s') = R(s, Q^2, s') (s + s' + Q^2) Q^2 a^{ll} (s, Q^2, s') ,$$

$$g_{CM}^{ll}(s, Q^2, s') = \frac{1}{M} R(s, Q^2, s') \xi(s, Q^2, s') Q^2 b^{ll} (s, Q^2, s') ,$$

$$a^{00} = \left( \frac{1}{2} \cos \omega_1 \cos \omega_2 + \frac{1}{6} \sin \omega_1 \sin \omega_2 \right), \quad a^{02} = -\frac{1}{6 \sqrt{2}} (P'_{22} + 2 P'_{20}) \sin \omega_1 \sin \omega_2 ,$$

$$a^{22} = \left[ \frac{1}{2} L_1 \cos \omega_1 \cos \omega_2 + \frac{1}{24} L_2 \sin (\omega_2 - \omega_1) + \frac{1}{12} L_3 \sin \omega_1 \sin \omega_2 \right] ,$$

$$b^{00} = \left( \frac{1}{2} \cos \omega_1 \sin \omega_2 - \frac{1}{6} \sin \omega_1 \cos \omega_2 \right) , \quad b^{02} = \frac{1}{6 \sqrt{2}} (P'_{22} + 2 P'_{20}) \sin \omega_1 \cos \omega_2 ,$$

$$b^{22} = \left[ -\frac{1}{2} L_1 \cos \omega_1 \sin \omega_2 + \frac{1}{24} L_2 \cos (\omega_2 - \omega_1) + \frac{1}{12} L_3 \sin \omega_1 \cos \omega_2 \right] ,$$

$$R(s, Q^2, s') = \frac{(s + s' + Q^2)}{\sqrt{(s - 4M^2)(s' - 4M^2)}} \frac{\vartheta(s, Q^2, s')}{[\lambda(s, -Q^2, s')]^{3/2}} \frac{1}{\sqrt{1 + Q^2/4M^2}} ,$$

$$\xi(s, Q^2, s') = \sqrt{ss'Q^2 - M^2 \lambda(s, -Q^2, s')} , \quad \lambda(a, b, c) = a^2 + b^2 + c^2 - 2(ab + ac + bc) ,$$

$$L_1 = L_1(s, Q^2, s') = P'_{20} + \frac{1}{3} P_{21} P'_{21} + \frac{1}{12} P_{22} P'_{22} ,$$

$$L_2 = L_2(s, Q^2, s') = P_{21} (P'_{22} - 6 P_{20}) - P'_{21} (P_{22} - 6 P_{20}) ,$$

$$L_3 = L_3(s, Q^2, s') = 2 P_{21} P'_{21} + 4 P_{20} P'_{20} - P_{20} P_{22} - P_{22} P_{20} .$$

Here $\omega_1$ and $\omega_2$ are the Wigner spin rotation parameters:

$$\omega_1 = \arctan \frac{\xi(s, Q^2, s')}{M \left[ (\sqrt{s} + \sqrt{s'})^2 + Q^2 \right] + \sqrt{ss'}(\sqrt{s} + \sqrt{s'})} ,$$

$$\omega_2 = \arctan \frac{\alpha(s, s') \xi(s, Q^2, s')}{M (s + s' + Q^2) \alpha(s, s') + \sqrt{ss'}(4M^2 + Q^2)} ,$$

and $\alpha(s, s') = 2M + \sqrt{s} + \sqrt{s'}$.

$P_{2i} = P_{2i}(z)$, $P'_{2i} = P_{2i}(z')$, $i = 0, 1, 2$ - the Legendre functions:

$$P_{20}(z) = \frac{1}{2} \left( 3 z^2 - 1 \right) , \quad P_{21}(z) = 3 \sqrt{1 - z^2} , \quad P_{22}(z) = 3 \left( 1 - z^2 \right) .$$

$$z = z(s, Q^2, s') = \frac{\sqrt{s'(s - Q^2)}}{\sqrt{\lambda(s, -Q^2, s')(s - 4M^2)}} , \quad z' = z'(s, Q^2, s') = -z(s', Q^2, s) .$$
\[ \psi(s, Q^2, s') = \theta(s' - s_1) - \theta(s' - s_2), \] \[ s_{1,2} = 2M^2 + \frac{1}{2M^2}(2M^2 + Q^2)(s - 2M^2) \mp \frac{1}{2M^2}\sqrt{Q^2(Q^2 + 4M^2)}s(s - 4M^2). \] \[ (10) \]

The functions \( s_{1,2}(s, Q^2) \) give the kinematically available region in the plane \((s, s')\) (see [27]).

\[ g_{C1}^{il}(s, Q^2, s) = g_{C1}^{il}(s', Q^2, s), \quad i = C, M. \] \[ (11) \]

Using Eq. (1) one can write the neutron charge form factor in the form:

\[ G_E^n(Q^2) = \frac{G_C(Q^2)}{G_{CC}(Q^2)} - \frac{G_{CM}(Q^2)}{G_{CC}(Q^2)} \left[ G_M^p(Q^2) + G_M^n(Q^2) \right] - G_E^p(Q^2). \] \[ (12) \]

We calculate the nucleon charge form factor in the points \( Q^2 \) where the deuteron charge form factor \( G_C(Q^2) \) is measured. In these points the nucleon form factors \( G_E^p(Q^2), G_M^p(Q^2), G_M^n(Q^2) \) are obtained through the fits of their experimental values. The functions \( G_{CC}(Q^2), G_{CM}(Q^2) \) can be calculated using the equations (3), (4) and some deuteron wave functions.

Let us discuss now the problem of choosing the deuteron wave functions to use for the calculation of \( G_{CC}(Q^2), G_{CM}(Q^2) \) (12). We investigated the behavior of \( T_{20}(Q^2) \) (our determination of \( T_{20}(Q^2) \) is the same as in [17]) using different wave functions\(^\dagger\): Paris wave functions [28], the versions I, II and 93 of the Nijmegen model [29], charge–dependent version of Bonn potential [30], and the wave functions obtained by the relativistic dispersion variant of the inverse scattering method [31]. As \( T_{20}(Q^2) \) for polarized \( ed \) scattering depends weakly on the form of nucleon form factors one can use the experimental data for \( T_{20}(Q^2) \) to choose the most adequate deuteron wave functions. Fig.1 presents the results of our calculation of \( T_{20}(Q^2) \) with the use of the wave functions [28, 29, 30, 31] and nucleon form factors from [15] as well as the experimental points from the papers [17, 18, 19, 32, 33, 34, 35].

One can see that the best description of \( T_{20}(Q^2) \) is given by the wave functions [31].

Our estimations show that other wave functions (e.g. used in [30, 37]) also give poorer description of \( T_{20}(Q^2) \) than the wave functions [31].

Let us emphasize that the wave functions [31] were obtained more than 20 years ago and so no possible fitting reasons for \( T_{20}(Q^2) \) could influence the choose. These wave functions used in the relativistic calculation of the function \( A(Q^2) \) give the correct behavior up to \( Q^2 \approx 3 \) (GeV\(^2\)).

It seems to us that the validity of the wave functions [31] is due to the fact that they are ”almost model independent”: no form of \( NN \) interaction Hamiltonian is used. The

\(^\dagger\) The details will be published elsewhere.
wave functions \[31\] were obtained in the frame of the potentialless approach to the inverse scattering problem (see for the details \[38\]). They are given by the dispersion type integral directly in terms of the experimental scattering phases and the mixing parameter for $NN$ scattering in the $^3S_1 - ^3D_1$ channel.

In the Eq.(12) we use for the nucleon factors $G_E^p(Q^2)$, $G_M^p(Q^2)$, $G_M^n(Q^2)$ one (with the best $\chi^2$) of the fits of the recent paper \[33\] – DRN–GK(3).

The results of our calculations of the neutron charge form factor in the points where the deuteron charge form factor is measured are given in the Table 1 (see also Fig.2).

The accuracy of our calculations are determined by the accuracy of measurements of charge deuteron form factor \[17, 18, 19\] and nucleon form factors which are the following at $Q^2 \leq 1.717$ (GeV$^2$): for $G_E^p(Q^2)$ 1–10\% \[11, 10, 11, 12\], for $G_M^p(Q^2)$ 1–3\% \[11, 11, 12, 13, 14\], for $G_M^n(Q^2)$ 1–10\%. \[4, 13, 13, 47, 48\].

We obtain the first three points at low momentum transfer from the data for the deuteron charge form factor given in the paper \[18\]. In this range of momentum transfer the behavior of the deuteron charge form factor and so $G_E^n(Q^2)$ do not depend on the choose of the wave functions \[28, 29, 30, 31\].

The first point at $Q^2 \simeq 0.16$ (GeV$^2$) is almost the same as in \[3\], however, our errors are much smaller. The second and the third points are compatible (within the experimental errors) with the points of \[7, 8, 11\]. Our point # 7 is in fact the same as in \[11\] but our error is larger.

Our values of $G_E^n$ in other points (at $Q^2 \geq 1$ (GeV$^2$)) are strictly positive. This result differs from e.g. the results of the paper \[11\] consistent with $G_E^n = 0$. Let us note that our errors at $Q^2 \geq 1$ (GeV$^2$) are sufficiently small, smaller than, e.g. in \[11, 11\].

Our values # 4–8 are extracted from the values of charge deuteron form factor of the two different works \[17, 19\]. The results of these works are in rather poor agreement with each other in the region of the first dip. So the values of # 4–8 of $G_E^n$ are not well determined in the present work. One needs additional experiments in this region.

It is now interesting to fit all the existing values of neutron charge form factor (\[4, 3, 4, 4, 1, 1, 1, 1, 1, 1, 1\] and Table 1). We use for the fitting the following function (see \[15\] and the review \[21\]) with two parameters $a$ and $b$:

$$G_E^n(Q^2) = -\mu_n \frac{a \tau}{1 + b \tau} G_D(Q^2), \quad G_D(Q^2) = \left(1 + \frac{Q^2}{0.71}\right)^{-2}, \quad \tau = \frac{Q^2}{4 M^2}. \quad (13)$$

The neutron magnetic moment $\mu_n = -1.91304270(5)$ \[19\]. $Q^2$ in $G_D(Q^2)$ is given in (GeV$^2$).

We obtain the parameter $a$ from the slope of the neutron charge form factor at $Q^2 = 0$
\[ \frac{dG^n_E}{dQ^2} \bigg|_{Q^2=0} = 0.0199 \pm 0.0003 \text{ fm}^2. \] (14)

The fitting of the slope (14) gives \( a = 0.942 \) with the accuracy \( \approx 1.5\% \).

This value of \( a \) gives the slope of \( G^n_E(Q^2) \) at \( Q^2 = 0 \) which is measured directly in the experiment.

The parameter \( b \) is fitted using the \( \chi^2 \) criterion. If we use all the 35 points we obtain \( b = 4.61 \) with \( \chi^2 = 69.0 \). Note that the fit DRN–GK(3) \[39\] of 23 points has \( \chi^2 = 63.9 \).

If we exclude the points \#4–8 then the 30-point fitting gives \( b = 4.62 \) with \( \chi^2 = 61.5 \). As the errors of these points are large this fitting differs from the previous one slightly.

Let us note that our fitting for 23 points of the papers \[1, 3, 4, 5, 6, 7, 8, 9, 10, 11\] (not taking into account our points) gives \( b = 4.69 \) with \( \chi^2 = 57.7 \). The two curves lie near one another (see Fig.2) so our points are consistent with the known points of other authors.

The results of fitting, the experimental points \[1, 3, 4, 5, 6, 7, 8, 9, 10, 11\], as well as our new points are shown on the Fig.2. The points \#5 and \#6 are out of the figure.

To summarize,

1) We extract new points for the neutron charge form factor from the experimental data for the deuteron charge form factor. The obtained values are consistent with the known values of other authors.

2) We perform the fitting for 35 values of the neutron charge form factor including our points. The fit has the form (13) with \( a = 0.942, b = 4.61 \).

This work was supported in part by the Program “Russian Universities – Basic Researches” (grant \# 02.01.28).

**References**

[1] K.M. Hanson et al., Phys.Rev.D 8 (1973) 753.
[2] V.M. Muzafarov and V.E. Troitsky, Yad.Fiz. 33 (1981) 1396.
[3] C.E. Jones-Woodward et al., Phys.Rev.C 44 (1991) R571.
[4] A. Lung et al., Phys.Rev.Lett. 70 (1993) 718.
[5] T. Eden et al., Phys.Rev.C 50 (1994) R1749.
[6] M. Meyerhoff et al., Phys.Lett.B 327 (1994) 201.
[7] I. Passchier et al., Phys.Rev.Lett. 82 (1999) 4988.
[8] M. Ostrick et al., Phys.Rev.Lett. 83 (1999) 276.
[9] D. Rohe et al., Phys.Rev.Lett. 83 (1999) 4257.
[10] C. Herberg et al., Eur.Phys.J A 5 (1999) 131.
[11] J. Golak et al., Phys.Rev.C 63 (2001) 034006.
[12] E. Tomasi–Gustafsson and M.P. Rekalo, Eurphys.Lett. 55 (2001) 188.
[13] R. Schiavilla and I. Sick, Phys.Rev.C 64 (2001) 041002.
[14] S. Kopecky, P. Riehs, J.A. Harvey, and N.W. Hill, Phys.Rev.Lett. 74 (1995) 2427.
[15] S. Galster et al., Nucl.Phys. B 32 (1971) 221.
[16] S. Platchkov et al., Nucl.Phys. A 510 (1990) 740.
[17] I. The et al., Phys.Rev.Lett. 67 (1991) 173.
[18] M. Bouwhuis et al., Phys.Rev.Lett. 82 (1999) 3755.
[19] D. Abbott et al., Phys.Rev.Lett. 84 (2000) 5053.
[20] W.N. Polyzou, Ann.Phys. 193 (1989) 367; B.D. Keister and W. Polyzou, Adv.Nucl.Phys. 21 (1991) 225; F. Coester, Progr. in Part. and Nucl.Phys. 29 (1992) 1; F.M. Lev, Rev. Nuovo Cim. 16 (1993) 1.
[21] M. Garcon and J.W. Van Orden, Adv.Nucl. Phys. 26 (2001) 293.
[22] R. Gilman and F.Gross, Electromagnetic structure of the deuteron, Preprint JLAB–PHY–01–25, WM–01–113, arXiv: nucl-th/0111015.
[23] A.F. Krutov and V.E. Troitsky, Phys. Rev. C (to be published).
[24] E.V. Balandina, A.F. Krutov, and V.E. Troitsky, Teor. Math. Phys. 103 (1995) 381; E.V. Balandina, A.F. Krutov, and V.E. Troitsky, J. Phys. G: Nucl. Part. Phys. 19 (1996) 1585; A.F. Krutov, Yad. Fiz. 60 (1997) 1442 [Phys. At. Nuclei 60 (1997) 1305.]; A.F. Krutov and V.E. Troitsky, JHEP 10 (1999) 028; A.F.Krutov, O.I.Shro, and V.E.Troitsky, Phys.Lett.B 502 (2001) 140.
[25] A. F. Krutov and V.E. Troitsky, in preparation.
[26] A.V. Afanasev, V.D. Afanas’ev, and S.V. Trubnikov, Relativistic Charge Form Factor of the Deuteron, Preprint JLAB-THY-98-01, arXiv:nucl-th/9712082.
[27] V.E. Troitsky and Yu.M. Shirokov, Theor. Math. Fiz. 1 (1969) 213.
[28] M. Lacomb, B. Loiseau, R. Vinh Mau, J. Coté, P. Pirés, and R. de Tourreil, Phys.Lett.B 101 (1981) 139.
[29] V.G.J. Stoks, R.A.M. Klomp, C.P.F. Terheggen, and J.J. de Swart, Phys.Rev.C 49 (1994) 2950.
[30] R. Machleidt, Phys.Rev.C 63 (2001) 024001.
[31] V.M. Muzafarov and V.E. Troitsky, Yad.Fiz. 33 (1981) 1461.
[32] M.E. Schulze et al, Phys.Rev.Lett. 52 (1984) 597.
[33] V.F. Dmitriev et al, Phys.Lett.B 157 (1985) 143.
[34] R. Gilman et al, Phys.Rev.Lett. 65 (1990) 1733.
[35] M. Ferro–Luzzi et al., Phys.Rev.Lett. 77 (1996) 2630.
[36] F.M. Lev, E. Pacé and G. Salmé, Phys.Rev.C 62 (2000) 064004.
[37] T.W. Allen, W.H. Klink and W.N. Polyzou, Phys.Rev.C 63 (2001) 034002.
[38] V.E. Troitsky, Lect.Not.Phys. 467 (1994) 50.
[39] E.L. Lomon, Phys.Rev.C 64 (2001) 035204.
[40] J.J. Murphy, Y.M. Shin, and D.M. Skopik, Phys.Rev.C 9 (1974) 2125.
[41] R.C. Walker et al., Phys.Rev.D 49 (1994) 5671.
[42] L. Andivahis et al., Phys.Rev.D 50 (1994) 5491.
[43] W. Bartel et al., Nucl.Phys.B 58 (1973) 429.
[44] P.E. Bosted et al., Phys.Rev. C 42 (1990) 38.
[45] P. Markowitz et al., Phys.Rev. C 48 (1993) R5.
[46] H. Gao et al., Phys.Rev. C 50 (1994) R546.
[47] H. Anklin et al., Phys.Lett. B 428 (1998) 248.
[48] W. Xu et al., Phys.Rev.Lett. 85 (2000) 2900.
[49] D.E. Groom et al., Eur.Phys.J. C 15 (2000) 1.
Table 1. The values of $G_E^p(Q^2)/G_D(Q^2)$ obtained in the present paper. The values of the deuteron charge form factor used for the extraction of $G_E^p(Q^2)$ are also given.

| # of points | $Q^2$ (GeV$^2$) | $G_C(Q^2)$ | Ref. | $G_E^p(Q^2)/G_D(Q^2)$ |
|-------------|----------------|------------|------|------------------------|
| 1           | 0.160          | 0.163±0.017| [18] | 0.076±0.116            |
| 2           | 0.215          | 0.100±0.012| [18] | 0.052±0.129            |
| 3           | 0.303          | 0.035±0.020| [18] | -0.234±0.401           |
| 4           | 0.556          | (0.127±0.047)·10$^{-1}$ | [17] | 1.23±0.92               |
| 5           | 0.651          | (-0.117±0.162)·10$^{-2}$ | [19] | -2.61±1.65              |
| 6           | 0.693          | (0.166±0.161)·10$^{-2}$ | [17] | -4.52±5.10              |
| 7           | 0.775          | (-0.253±0.063)·10$^{-2}$ | [19] | 0.677±0.361             |
| 8           | 0.831          | (-0.147±0.100)·10$^{-2}$ | [17] | -0.140±0.432            |
| 9           | 1.009          | (-0.396±0.028)·10$^{-2}$ | [19] | 0.389±0.107             |
| 10          | 1.165          | (-0.348±0.031)·10$^{-2}$ | [19] | 0.259±0.131             |
| 11          | 1.473          | (-0.310±0.061)·10$^{-2}$ | [19] | 0.405±0.263             |
| 12          | 1.717          | (-0.194±0.036)·10$^{-2}$ | [19] | 0.174±0.294             |
Fig. 1. Data and the results of calculation of the deuteron polarization tensor $T_{20}(Q^2)$ for the elastic $ed$–scattering with the use of the nucleon form factors from the paper [15] and different wave functions. The experimental points are: open circles – [32], open squares – [35], open triangles – [34], filled circles – [17], filled squares – [18], filled diamonds – [19], filled triangles – [33]. Curves: solid – Nijmegen–II [29], dashed – [31], dotted – [28], dash–dotted – Nijmegen–I [29], dash–dotted–dotted – [30].

Fig. 2. The experimental values and the results of fitting for the neutron charge form factor. The experimental points: bold cross – [5], open bold diamonds – [11], open up triangles – [8], open circles – [4], open down triangles – [6], open stars – [10], filled circles – [3], filled diamonds – [9], filled up triangles – [3], filled stars – [1], filled squares – the present work. The points # 5 and # 6 are out of the figure. The curves: solid – the result of fitting of 35 experimental points (including our points of the Table 1) using the equation (13) ($a = 0.942$, $b = 4.61$ with $\chi^2 = 69.0$), dashed – the result of fitting of 23 points of other authors ($a = 0.942$, $b = 4.69$ with $\chi^2 = 57.7$).

Figures capture.
FIG. 1.
FIG. 2.