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Extraction of the neutron charge form factor $G_E^n(Q^2)$ from the charge form factor of deuteron $G_C^d(Q^2)$

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Abstract. We extract the neutron charge form factor $G_E^n(Q^2)$ from the charge form factor of deuteron $G_C^d(Q^2)$ obtained from $T_{20}(Q^2)$ data at $0 \leq Q^2 \leq 1.717$ (GeV/c)^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 (36 points) taking into account the data for the slope of the form factor at $Q^2 = 0$.

PACS. 14.20.Dh Properties of specific particles: protons and neutrons – 13.40.Gp Specific reactions and phenomenology: electromagnetic form factors

The behavior of the neutron charge (electric) form factor $G_E^n(Q^2)$, ($Q^2 = -q^2$, q is 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. The major difficulty faced in a measurement of neutron form factors is the lack of a free-neutron target. $G_E^n(Q^2)$ has to be extracted from the data for composite nuclei, for example deuteron or ^{3}He [1–15]. The direct measurement of great precision ($\simeq 1.5\%$) is possible only for the slope $\mathrm{d}G_E^n(Q^2)/\mathrm{d}Q^2$ at $Q^2 = 0$, as determined by thermal-neutron scattering [16].

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 [15,17,18]. Second, there exists a dependence on the relativistic effects, exchange currents, nucleon isobar states, final-state interaction in inelastic channels etc. [3,14]. The use of polarized beams and polarized targets in recent experiments diminishes uncertainties due to those effects [2–4,6–8,11,15].

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 [19–21]. 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 the JLab experiments [21] the deuteron charge form factor is obtained up to $Q^2 = 1.717$ (GeV/c)^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. All modern relativistic calculations of the deuteron structure in terms of nucleon degrees of freedom are based on two main classes of approaches [22,23] (especially see fig. 11 of [23]). The first class is based on field-theoretical concepts (following paper [23] —propagator dynamics). This class contains the Bethe-Salpeter equation and quasipotential approaches. The second-class relativistic Hamiltonian dynamics (RHD) is based on the realization of the Poincaré algebra on the set of dynamical observables of the system with a finite numbers of degrees of freedom. One can find the description of RHD method in the reviews [24] (see also [25]) and especially the case of deuteron in the reviews [22,23]. As is noted in [23], the connection between the propagator dynamics and RHD is ambiguous. Each of the approaches has its own advantages as well as difficulties. Our calculations are based on the method of relativistic Hamiltonian dynamics. We use our own variant [26], of the instant form of RHD (see also [27,28]). This variant permits to take correctly into account the relativistic effects in the elastic *ed* scattering in the relativistic impulse approximation using the method proposed in [26]. The main feature of this approach is the method of construction of the matrix element of the electroweak current operator. The electroweak current matrix element satisfies the relativistic covariance conditions and in the case

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of the electromagnetic current also the conservation law automatically. The properties of the system as well as the approximations are formulated in terms of form factors. The approach makes it possible to formulate relativistic impulse approximation in such a way that the Lorentz covariance of the current is ensured. In the electromagnetic case the current conservation law is also ensured.

In our approach in the relativistic impulse approximation using the method [26] one can obtain the following equation for the deuteron charge form factor:

$$G_C^d(Q^2) = G_{CC}(Q^2)\left[G_E^p(Q^2) + G_E^n(Q^2)\right] + G_{CM}(Q^2)\left[G_M^p(Q^2) + G_M^n(Q^2)\right] . \quad (1)$$

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

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

$$G_{CC}(Q^2) = \sum_{l,l'}\int \mathrm{d}\sqrt{s}\,\mathrm{d}\sqrt{s'}\,\varphi^l(s)\,g_{CC}^{ll'}(s,Q^2,s')\,\varphi^{l'}(s'), \quad (2)$$

$$G_{CM}(Q^2) = \sum_{l,l'}\int \mathrm{d}\sqrt{s}\,\mathrm{d}\sqrt{s'}\,\varphi^l(s)\,g_{CM}^{ll'}(s,Q^2,s')\,\varphi^{l'}(s'), \quad (3)$$

here $\varphi^l(s)$ is the wave function in the sense of RHD (see [26]):

$$\varphi^l(s) = \sqrt[4]{s}\,u_l(k)\,k\,, \quad k = \frac{1}{2}\sqrt{s-4\,M^2}\,,$$
$$\sum_l \int u_l^2(k)\,k^2\,\mathrm{d}k = 1\,, \quad (4)$$

M is the nucleon mass, $l = 0,\ 2$ the nucleon angular momentum in the deuteron, $u_l(k)$ the wave function for the model NN interaction. The functions $g_{CC}^{ll'}$, $g_{CM}^{ll'}$ are given by the following equations (5)–(10) (note that the same equations were obtained independently in [29]):

$$g_{CC}^{ll'}(s,Q^2,s') = R(s,Q^2,s')\,(s+s'+Q^2)\,Q^2 \times a^{ll'}(s,Q^2,s'), \quad (5)$$

$$g_{CM}^{ll'}(s,Q^2,s') = \frac{1}{M}\,R(s,Q^2,s')\xi(s,Q^2,s')\,Q^2 \times b^{ll'}(s,Q^2,s')\,, \quad (6)$$

$$a^{00} = \left(\frac{1}{2}\cos\omega_1\cos\omega_2 + \frac{1}{6}\sin\omega_1\sin\omega_2\right)\,,$$

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

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

$$b^{00} = \left(\frac{1}{2}\cos\omega_1\sin\omega_2 - \frac{1}{6}\sin\omega_1\cos\omega_2\right)\,,$$

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

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

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

$$\xi(s,Q^2,s') = \sqrt{ss'Q^2 - M^2\lambda(s,-Q^2,s')}\,,$$

$$\lambda(a,b,c) = a^2+b^2+c^2-2(ab+ac+bc)\,,$$

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

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

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

Here ω_1 and ω_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 $\alpha(s,s') = 2M + \sqrt{s} + \sqrt{s'}$.

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

$$P_{20}(z) = \frac{1}{2}\left(3\,z^2-1\right)\,, \quad P_{21}(z) = 3\,z\sqrt{1-z^2}\,,$$
$$P_{22}(z) = 3\left(1-z^2\right)\,. \quad (7)$$

$$z = z(s,Q^2,s') = \frac{\sqrt{s}(s'-s-Q^2)}{\sqrt{\lambda(s,-Q^2,s')(s-4\,M^2)}}\,,$$
$$z' = z'(s,Q^2,s') = -\,z(s',Q^2,s)\,. \quad (8)$$

$\vartheta(s,Q^2,s') = \theta(s'-s_1) - \theta(s'-s_2)$, θ is the step function;

$$s_{1,2} = 2M^2 + \frac{1}{2M^2}(2M^2+Q^2)(s-2M^2) \mp\frac{1}{2M^2}\sqrt{Q^2(Q^2+4M^2)s(s-4M^2)}\,. \quad (9)$$

The functions $s_{1,2}(s,Q^2)$ give the kinematically available region in the plane (s,s') (see [26,30]).

$$g_{Ci}^{ll'}(s,Q^2,s') = g_{Ci}^{l'l}(s',Q^2,s)\,, \quad i = C, M\,. \quad (10)$$

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

$$G_E^n(Q^2) = \frac{G_C^d(Q^2)}{G_{CC}(Q^2)} - \frac{G_{CM}(Q^2)}{G_{CC}(Q^2)} \times \left[G_M^p(Q^2) + G_M^n(Q^2)\right] - G_E^p(Q^2) . \quad (11)$$

We calculate the nucleon charge form factor in the points Q^2, where the deuteron charge form factor $G_C^d(Q^2)$ is measured. In these points the nucleon form factors

$$G_E^p(Q^2) , \quad G_M^p(Q^2) , \quad G_M^n(Q^2)$$

are obtained through the fits of their experimental values. The functions $G_{CC}(Q^2)$, $G_{CM}(Q^2)$ can be calculated using eqs. (2), (3) and some deuteron wave functions.

Let us discuss now the problem of choosing the deuteron wave functions to use for the calculation of $G_{CC}(Q^2)$, $G_{CM}(Q^2)$ (11).

Today there exist a number of models for the NN interaction potential. Some of them are: Paris potential [31], the versions I, II and 93 of the Nijmegen model [32], charge-dependent version of Bonn potential [33]. The deuteron wave functions for these potentials give the results for deuteron electromagnetic properties that differ essentially from one another. It is a difficult task to give the preference to one of them.

Quite different kind present the deuteron wave functions (MT) [34] obtained in the frame of the potentialless approach to the inverse scattering problem (see [35] for details).

The important feature of these wave functions is the fact that they are "almost model independent": no form of NN interaction Hamiltonian is used. The MT wave functions 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. A Regge analysis of the experimental data on NN scattering was used to describe the phase shifts at large energy.

It is worth to notice that the MT wave functions were obtained using quite general assumptions about analytical properties of quantum amplitudes such as the validity of the Mandelstam representation for the deuteron electrodisintegration amplitude. These wave functions have no fitting parameters and can be altered only with the amelioration of the NN scattering phase analysis. The MT wave functions were used in nonrelativistic calculation of deuteron form factors [36] and for the relativistic deuteron structure in [13,37].

Let us notice that the process of constructing these wave functions is closely related to the equations obtained in the framework of the dispersion approach based on the analytic properties of the scattering amplitudes [30,38–40] (see also [26] and especially the detailed version [41]). In fact, this approach is a kind of dispersion technique using integrals over composite-system masses.

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 (our determination of $T_{20}(Q^2)$ is the same as in [19]). Figure 1 presents the results of our calculation of $T_{20}(Q^2)$ with the use of the wave functions [31–34] and nucleon form factors from [23] as well as the experimental points from the papers [19–21,42–45].

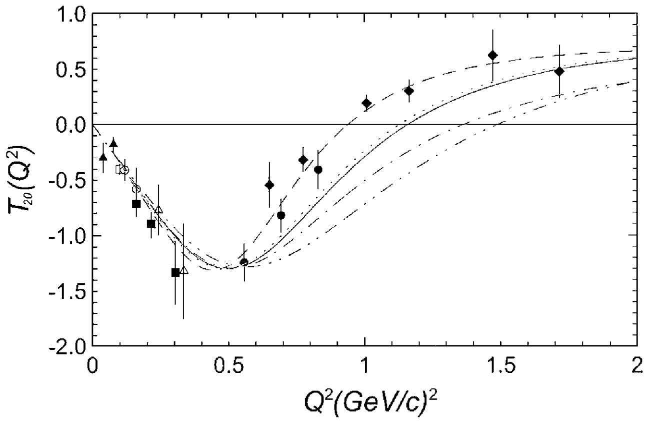

Fig. 1. Data and the results of calculation of the deuteron polarization tensor $T_{20}(Q^2)$ for the elastic ed scattering with the use of the nucleon form factors from the paper [17] and different wave functions. The experimental points are: open circles [42], open squares [45], open triangles [44], filled circles [19], filled squares [20], filled diamonds [21], filled triangles [43]. Curves: solid: Nijmegen–II [32], dashed: MT [34], dotted: [31], dash-dotted: Nijmegen–I [32], dash-double-dotted: [33].

One can see that the best description of $T_{20}(Q^2)$ is given by the wave functions [34].

Our estimations show that other wave functions (*e.g.*, used in [46,47]) also give poorer description of $T_{20}(Q^2)$ than the MT wave functions [34]. Let us emphasize that the MT wave functions [34] were obtained more than 20 years ago and so no possible fitting reasons for $T_{20}(Q^2)$ could influence the choice. To extract the neutron charge form factor from the deuteron charge form factor in an "almost model independent" way, we will use MT wave functions [34]. These wave functions used in the relativistic calculation of the function $A(Q^2)$ for the elastic ed scattering give the correct behavior up to $Q^2 \simeq 3$ (GeV/c)^2 (see fig. 2).

Let us discuss briefly the problem of meson exchange currents (MEC) which can cause some ambiguities in deuteron calculations [23]. It is accepted generally that one has to take MEC into account in a way compatible with the basic principles of the chosen approach. So, the value of the MEC corrections is different for different approaches. We hope that we can neglect MEC in our approach when the relativistic corrections are small. The base for this is the following theorem (Siegert, [48]; see especially the case of deuteron in [49]). If the electromagnetic current satisfies the conservation law in the differential form and if the dynamics of the two-particle system is nonrelativistic (the Schrödinger equation, the potential) then the charge density of the exchange current (the null component) is zero independently of the kind of the potential. So, in the range of the energy where the nonrelativistic dynamics is valid (the continuity equation is valid everywhere) the exchange current contributions to

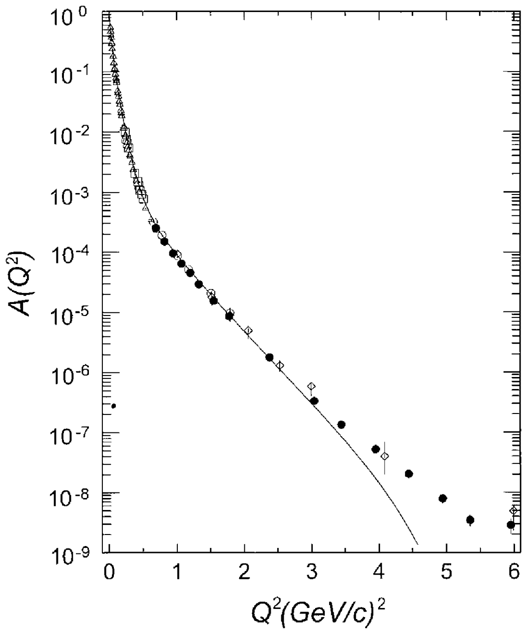

Fig. 2. Data and the results of calculation of the function $A(Q^2)$ for the elastic *ed* scattering with the use of the nucleon form factors from the paper [17] and wave functions MT from ref. [34]. The experimental points are the same as in ref. [46].

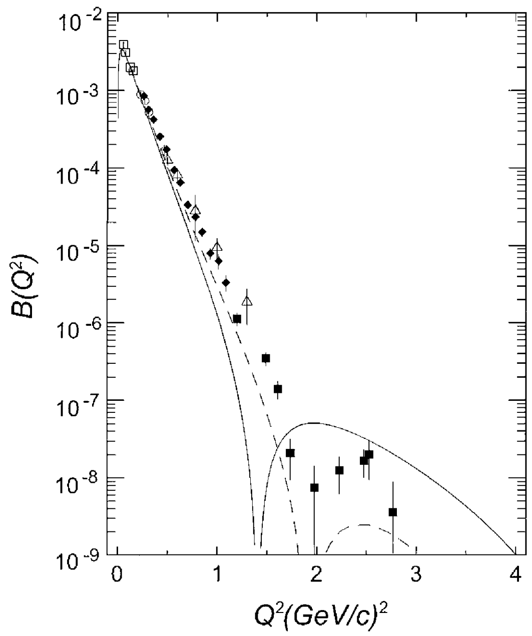

Fig. 3. Data and the results of calculation of the function $B(Q^2)$ for the elastic *ed* scattering with the use of the nucleon form factors from the paper [17] and wave functions MT from ref. [34]. The experimental points are the same as in ref. [46]. The solid line represents the calculation in MIA, the dashed line the calculation with $\rho\pi\gamma$ contribution from ref. [50]. $\rho\pi\gamma$ form factor is from ref. [23].

the charge and quadrupole form factors are zero. We suppose that when the nonrelativistic dynamics is valid approximately then the MEC contributions are small. In fact the relativistic contributions to the deuteron form factors in our approach are small in the region under consideration $Q^2 \leq 1.717$ (GeV/c)^2. Namely, the relativistic calculations with different wave functions [31–34] give a relativistic correction of about 10% at $Q^2 \simeq 1.7$ (GeV/c)^2. At smaller values of Q^2 the corrections are even smaller. So, it will be consistent with our approach not to take into account the meson exchange currents in the charge and quadrupole deuteron form factors. But the contribution of the MEC to the magnetic form factor can be important in the region under consideration.

Usually it is supposed that it is necessary to take MEC into account in order to provide the gauge invariance and the current conservation [24]. However today the construction of the relativistic impulse approximation without breaking the relativistic covariance and current conservation law is a common trend of different approaches [23, 25,26,46,47]. In our approach this is realized through the use of the Wigner-Eckart theorem for the Poincaré group. It enables one for given current matrix element to separate the reduced matrix elements (form factors) which are invariant under the Poincaré group action. The matrix element of a given operator is represented as a sum of terms, each one of them being a covariant part multiplied by an invariant part. In such a representation the covariant part describes the transformation properties of the matrix element. The conservation law is satisfied explicitly due to the fact that the vector of the covariant part is orthogonal to the vector Q_μ. All the dynamical information on the transition is contained in the invariant-part form factors. In our variant of the impulse approximation (modified impulse approximation) the reduced matrix elements are calculated with no change of covariant part (for details see [26]) although neglecting MEC (see eqs. (5)–(10)). The right transformation properties are thus guaranteed.

In fig. 3 the results of the calculation of the function $B(Q^2)$ for the elastic *ed* scattering are shown. $B(Q^2)$ depends on the magnetic form factor only. We use the MT wave functions and take into account the $\rho\pi\gamma$ exchange currents. The $\rho\pi\gamma$ form factor is taken from [23]. The results are consistent with the data at $Q^2 \leq 2$ (GeV/c)^2. The results given in the figs. 1–3 show that the MT wave functions describe the deuteron electromagnetic properties adequately at $Q^2 \leq 2$ (GeV/c)^2.

In eq. (11) we use for the nucleon form factors $G_M^p(Q^2)$, $G_M^n(Q^2)$ one (with the best χ^2) of the fits of the recent paper [51] —DRN-GK(3).

Let us consider the proton charge form factor $G_E^p(Q^2)$. The recent measurement in Jefferson Lab [52] have shown that $G_E^p(Q^2)$ decreases with the increasing of Q^2 more rapidly than it was accepted previously. In our calculations we use a new parameterization (see, *e.g.*, [23]) taking into account this information:

$$G_E^p(Q^2) = \left(1.0 - 0.1262\,Q^2\right) G_D(Q^2)\,, \qquad (12)$$

$$G_D(Q^2) = \left(1 + \frac{Q^2}{0.71}\right)^{-2}.$$

Here Q^2 is given in (GeV/c)^2.

Table 1. The values of $G_E^n(Q^2)/G_D(Q^2)$ obtained in the present paper. The values of the deuteron charge form factor $G_C^d(Q^2)$ used for the extraction of $G_E^n(Q^2)$ are also given. Q^2 is given in (GeV/c)^2.

#	Q^2	G_C^d	Ref.	G_E^n/G_D
1	0.160	0.163 ± 0.017	[20]	0.020 ± 0.116
2	0.215	0.100 ± 0.012	[20]	-0.012 ± 0.129
3	0.303	0.035 ± 0.020	[20]	-0.305 ± 0.401
4	0.556	$(0.127^{+0.047}_{-0.056}) \cdot 10^{-1}$	[19]	1.17 ± 0.92
5	0.651	$(-0.117 \pm 0.162) \cdot 10^{-2}$	[21]	-2.66 ± 1.65
6	0.693	$(0.166^{+0.161}_{-0.142}) \cdot 10^{-2}$	[19]	-4.57 ± 5.10
7	0.775	$(-0.253 \pm 0.063) \cdot 10^{-2}$	[21]	0.642 ± 0.361
8	0.831	$(-0.147^{+0.106}_{-0.104}) \cdot 10^{-2}$	[19]	-0.167 ± 0.432
9	1.009	$(-0.396 \pm 0.028) \cdot 10^{-2}$	[21]	0.390 ± 0.107
10	1.165	$(-0.348 \pm 0.031) \cdot 10^{-2}$	[21]	0.287 ± 0.131
11	1.473	$(-0.310^{+0.053}_{-0.061}) \cdot 10^{-2}$	[21]	0.487 ± 0.263
12	1.717	$(-0.194^{+0.036}_{-0.052}) \cdot 10^{-2}$	[21]	0.300 ± 0.294

Let us remark that our variant of extraction of the neutron charge form factor is sensible to the value of the proton charge form factor (see eq. (11)). The result is slightly different, for example, (see our paper [53]) for the parameterization DRN-GK(3) from [51].

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. 4).

The accuracy of our calculations are determined by the accuracy of measurements of charge deuteron form factor [19–21] and nucleon form factors which are the following at $Q^2 \le 1.717$ (GeV/c)^2: for $G_E^p(Q^2)$ 1–10% [1,54–56], for $G_M^p(Q^2)$ 1–3% [1,55–58], for $G_M^n(Q^2)$ 1–10% [3, 59–62].

We obtain the first three points at low momentum transfer from the data for the deuteron charge form factor given in paper [20]. 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 choice of the wave functions [31–34].

The first, second and the third points are compatible (within the experimental errors) with the points of [4,6, 7,11]. Our point # 7 is in fact the same as in [1] but our error is larger.

Our values of G_E^n in other points (at $Q^2 \ge 1$ (GeV/c)^2 are strictly positive. This result differs from, *e.g.*, the results of paper [3] consistent with $G_E^n = 0$. Let us note that our errors at $Q^2 \ge 1$ (GeV/c)^2 are sufficiently small, smaller than, *e.g.*, in [1,3].

Our values # 4–8 are extracted from the values of charge deuteron form factor of the two different works [19, 21]. 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 to locate more precisely the position of the node of the charge deuteron form factor [22].

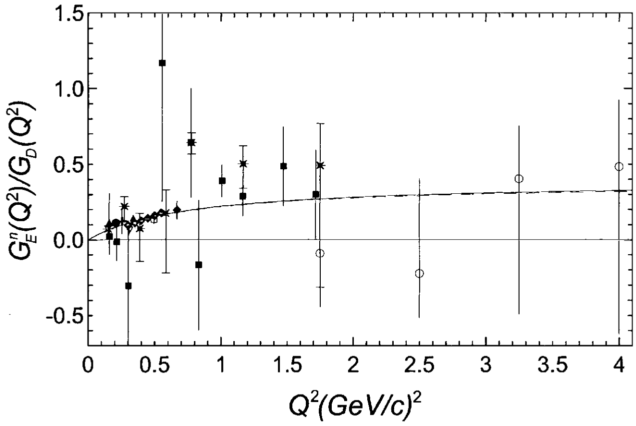

Fig. 4. The experimental values and the results of fitting for the neutron charge form factor. The experimental points: bold cross [4], open bold diamonds [11], open up triangles [7], open circles [3], open down triangles [5], open stars [9], open square [12], filled circles [6], filled diamonds [8], filled up triangles [2], filled stars [1], filled squares: the present work. The points # 5 and # 6 are out of the figure. The curves: solid is for the result of fitting of 36 experimental points (including our points of the table 1) using eq. (13) ($a = 0.942$, $b = 4.65$ with $\chi^2 = 70.8$), dashed for the result of fitting of 24 points of other authors ($a = 0.942$, $b = 4.74$ with $\chi^2 = 58.2$).

It is now interesting to fit all the existing values of neutron charge form factor ([1–9,11,12] and table 1). We use for the fitting the following function (see [17] and the review [22]) with two parameters a and b:

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

The neutron magnetic moment $\mu_n = -1.91304270(5)$ [63].

We obtain the parameter a from the slope of the neutron charge form factor at $Q^2 = 0$ [16,51]:

$$\left.\frac{\mathrm{d}G_E^n}{\mathrm{d}Q^2}\right|_{Q^2=0} = 0.0199 \pm 0.0003 \text{ fm}^2\;. \qquad (14)$$

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

This value of a gives the slope of $G_E^n(Q^2)$ at $Q^2 = 0$ which is measured directly in the experiment.

The parameter b is fitted using the χ^2 criterion. If we use all the 36 points we obtain $b = 4.65$ with $\chi^2 = 70.8$. Note that the fit DRN-GK(3) [51] of 23 points has $\chi^2 = 63.9$.

If we exclude the points # 4–8, then the 31-point fitting gives $b = 4.65$ with $\chi^2 = 63.5$. As the errors of these points are large this fitting differs from the previous one slightly.

Let us note that our fitting for 24 points of the papers [1–9,11,12] (not taking into account our points) gives $b = 4.74$ with $\chi^2 = 58.2$. The two curves lie near to one another (see fig. 4) so our points are consistent with the known points of other authors.

The results of fitting, the experimental points [1–9, 11, 12], as well as our new points are shown on the fig. 4. The points # 5 and # 6 are out of the figure.

To summarize,

1) We extract 12 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 36 values of the neutron charge form factor including our points. The fit has the form (13) with $a = 0.942$, $b = 4.65$.

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References

1. K.M. Hanson *et al.*, Phys. Rev. D **8**, 753 (1973).
2. C.E. Jones-Woodward *et al.*, Phys. Rev. C **44**, R571 (1991).
3. A. Lung *et al.*, Phys. Rev. Lett. **70**, 718 (1993).
4. T. Eden *et al.*, Phys. Rev. C **50**, R1749 (1994).
5. M. Meyerhoff *et al.*, Phys. Lett. B **327**, 201 (1994).
6. I. Passchier *et al.*, Phys. Rev. Lett. **82**, 4988 (1999).
7. M. Ostrick *et al.*, Phys. Rev. Lett. **83**, 276 (1999).
8. D. Rohe *et al.*, Phys. Rev. Lett. **83**, 4257 (1999).
9. C. Herberg *et al.*, Eur. Phys. J. A **5**, 131 (1999).
10. J. Becker *et al.*, Eur. Phys. J. A **6**, 329 (1999).
11. J. Golak *et al.*, Phys. Rev. C **63**, 034006 (2001).
12. H. Zhu *et al.*, Phys. Rev. Lett. **87**, 081801 (2001).
13. V.M. Muzafarov, V.E. Troitsky, Yad. Fiz. **33**, 1396 (1981).
14. E. Tomasi-Gustafsson, M.P. Rekalo, Eurphys. Lett. **55**, 188 (2001).
15. R. Schiavilla, I. Sick, Phys. Rev. C **64**, 041002 (2001).
16. S. Kopecky, P. Riehs, J.A. Harvey, N.W. Hill, Phys. Rev. Lett. **74**, 2427 (1995).
17. S. Galster *et al.*, Nucl. Phys. B **32**, 221 (1971).
18. S. Platchkov *et al.*, Nucl. Phys. A **510**, 740 (1990).
19. I. The *et al.*, Phys. Rev. Lett. **67**, 173 (1991).
20. M. Bouwhuis *et al.*, Phys. Rev. Lett. **82**, 3755 (1999).
21. D. Abbott *et al.*, Phys. Rev. Lett. **84**, 5053 (2000).
22. M. Garcon, J.W. Van Orden, Adv. Nucl. Phys. **26**, 293 (2001).
23. R. Gilman, F. Gross, J. Phys. G: Nucl. Part. Phys. **28**, R37 (2002).
24. B.D. Keister, W. Polyzou, Adv. Nucl. Phys. **20**, 225 (1991).
25. W.H. Klink, Phys. Rev. C **58**, 3587 (1998).
26. A.F. Krutov, V.E. Troitsky, Phys. Rev. C **65**, 045501 (2002).
27. A.F. Krutov, V.E. Troitsky, Eur. Phys. J. C **20**, 71 (2001).
28. E.V. Balandina, A.F. Krutov, V.E. Troitsky, Teor. Mat. Fiz. **103**, 381 (1995) (Theor. Math. Phys. **103**, 41 (1995)); E.V. Balandina, A.F. Krutov, V.E. Troitsky, J. Phys. G: **19**, 1585 (1996); A.F. Krutov, Yad. Fiz. **60**, 1442 (1997) (Phys. At. Nuclei **60**, 1305 (1997)); A.F. Krutov, V.E. Troitsky, JHEP **10**, 028 (1999); A.F.Krutov, O.I.Shro, V.E. Troitsky, Phys. Lett. B **502**, 140 (2001).
29. A.V. Afanasev, V.D. Afanas'ev, S.V. Trubnikov, *Relativistic Charge Form Factor of the Deuteron*, Preprint JLAB-THY-98-01, arXiv:nucl–th/9712082.
30. V.E. Troitsky, Yu.M. Shirokov, Theor. Math. Fiz. **1**, 213 (1969).
31. M. Lacomb, B. Loiseau, R. Vinh Mau, J. Coté, P. Pirés, R. de Tourreil, Phys. Lett. B **101**, 139 (1981).
32. V.G.J. Stoks, R.A.M. Klomp, C.P.F. Terheggen, J.J. de Swart, Phys. Rev. C **49**, 2950 (1994).
33. R. Machleidt, Phys. Rev. C **63**, 024001 (2001).
34. V.M. Muzafarov, V.E. Troitsky, Yad. Fiz. **33**, 1461 (1981).
35. V.E. Troitsky, Lect. Notes Phys. **467**, 50 (1994).
36. I.I. Belyantsev, V.K. Mitryushkin, P.K. Rashidov, S.V. Trubnikov, J. Phys. G: Nucl. Part. Phys. **9**, 871 (1983).
37. R.G. Arnold *et al.*, Phys. Rev. Lett. **58**, 1723 (1987).
38. A.I. Kirillov, V.E. Troitsky , S.V. Trubnikov, Yu.M. Shirokov, Fiz. Elem. Chastits At. Yad. **6**, 3 (1975) (Sov. J. Part. Nucl. **6**, 3 (1975)).
39. V.V. Anisovich, M.N. Kobrinsky, D.I. Melikhov, A.V.Sarantsev, Nucl. Phys. A **544**, 747 (1992).
40. V. Anisovich, D. Melikhov, V. Nikonov, Phys. Rev. D **52**, 5295 (1995).
41. A.F. Krutov, V.E. Troitsky, hep-ph/0101327.
42. M.E. Schulze *et al.*, Phys. Rev. Lett. **52**, 597 (1984).
43. V.F. Dmitriev *et al.*, Phys. Lett. B **157**, 143 (1985).
44. R. Gilman *et al.*, Phys. Rev. Lett. **65**, 1733 (1990).
45. M. Ferro-Luzzi *et al.*, Phys. Rev. Lett. **77**, 2630 (1996).
46. F.M. Lev, E. Pacé, G. Salmé, Phys. Rev. C **62**, 064004 (2000).
47. T.W. Allen, W.H. Klink, W.N. Polyzou, Phys. Rev. C **63**, 034002 (2001).
48. A.J.F. Siegert, Phys. Rev. **52**, 787 (1937).
49. H. Baier, Fortschr. Phys. **27**, 209 (1979).
50. M. Gari, H. Hyuga, Nucl. Phys.A **264**, 409 (1976).
51. E.L. Lomon, Phys. Rev. C **64**, 035204 (2001).
52. O. Gayon *et al.*, Phys. Rev. Lett. **88**, 092301 (2002).
53. A.F. Krutov, V.E. Troitsky, hep-ph/0202183.
54. J.J. Murphy, Y.M. Shin, D.M. Skopik, Phys. Rev. C **9**, 2125 (1974).
55. R.C. Walker *et al.*, Phys. Rev. D **49**, 5671 (1994).
56. L. Andivahis *et al.*, Phys. Rev. D **50**, 5491 (1994).
57. W. Bartel *et al.*, Nucl. Phys. B **58**, 429 (1973).
58. P.E. Bosted *et al.*, Phys. Rev. C **42**, 38 (1990).
59. P. Markowitz *et al.*, Phys. Rev. C **48**, R5 (1993).
60. H. Gao *et al.*, Phys. Rev. C **50**, R546 (1994).
61. H. Anklin *et al.*, Phys. Lett. B **428**, 248 (1998).
62. W. Xu *et al.*, Phys. Rev. Lett. **85**, 2900 (2000).
63. D.E. Groom *et al.*, Eur. Phys. J. C **15**, 1 (2000).