Relativistic corrections to the charge form factor of the deuteron at large momentum transfers

V. M. Muzafarov, V. E. Troitskii, and Yu. M. Shirokov

Institute of Nuclear Physics of the Moscow State University
(Submitted 31 March 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 9, 538–542 (5 May 1978)

An integral representation in terms of the phase shifts of triplet n-p scattering is used for the deuteron charge form factor G_c^d. The relativistic corrections to G_c^d are completely accounted for. It is shown that they make an appreciable contribution to G_c^d at large momentum transfers. The possibility of neglecting the spin-flip effect is noted.

PACS numbers: 13.40.Fn, 13.60.Fz

Recent results of the Stanford experiment on the measurements of the cross section of elastic *ed* scattering, carried out in the region of the squared momentum transfer q^2 up to 160 F^{-2},[1] have inspired increasing interest in the relativistic description of *ed* scattering. Calculations within the framework of nonrelativistic potential models followed by allowance for the relativistic corrections do not make it possible to describe satisfactorily the *ed* scattering at such large q^2. To make further progress in the theory of *ed* scattering it is necessary to develop a consistent relativistic approach. It was hoped that this can be done by dispersion methods. It has by now become clear, however, that in this way it is difficult to obtain reliable quantitative results at large q^2.

One of us[2] has proposed a new possible approach to the construction of a consistent relativistic theory of *ed* scattering. Further development of this approach and its possibility is reflected in the review.[3] In the present paper we investigate, within the framework of this approach, the influence of relativistic effects on G_c^d at q^2 up to 300 F^{-2}. The relativistic integral representation used by us for the s-wave form factor G_c^d is of the form[4]

$$G_c^d(q^2) = \frac{\Gamma^2}{B'^2(M_D^2)} \int_{4M^2}^{\infty} \frac{ds\,\Delta(s)}{s - M_D^2} \int_{s_1(s,t)}^{s_2(s,t)} \frac{ds'\,\Delta(s')F(s,s',t)}{s' - M_D^2} \tag{1}$$

where $(-t)=q^2$. The function $B(s)$ is the relativistic analog of the nonrelativistic Jost function and is expressed in terms of the $^3S_1$ phase of the triplet n-p scattering by the quadrature formula

$$B(s) = \left(1 - \frac{M_D^2 - 4M^2}{s - 4M^2}\right) \exp\left\{\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{dk\,\delta(k)}{k - \sqrt{s} - i0}\right\}. \tag{2}$$

The quantity $\Delta(s) = B(s+i0) - B(s-i0)$ determine the jump of the Jost function on the cut. The function $F(s,s',t)$ is the electromagnetic current of a non-interacting n-p system:

$$F(s, s', t) = \frac{(s+s'-t)(-t)}{\sqrt{(s-4M^2)(s'-4M^2)}} \frac{1}{\sqrt{\lambda^3(1-t/4M^2)}}$$

$$\times \left\{ 2(s+s'-t)\cos\phi\, G^s_{EN}(q^2) + \frac{1}{M}\sqrt{(-1)(M^2\lambda + ss't)}\sin\phi\, G^s_{MN}(q^2) \right\},$$

$$\phi = \text{arc tg}\left\{ \frac{\sqrt{(-1)(M^2\lambda + ss't)}\;(4M^2 - t - a^2)}{M(s+s'-t)a^2 + (4M^2 - t)[M(s+s'-t) + 2\sqrt{ss'}a]} \right\},$$

$$a = \sqrt{s} + \sqrt{s'} + 2M,$$

$$\lambda = s^2 + s'^2 + t^2 - 2(ss' + st + s't). \tag{3}$$

The integration limits in (1), which determine the position of the anomalous threshold of the deuteron, are given by the expression

$$s_{2,1}(s,t) = 2M^2 + (1/2M^2)(2M^2 - t)(s - 2M^2) \pm (1/2M^2)\sqrt{(-t)(4M^2 - t)s(s - 4M^2)}.$$

In formulas (1)–(3), M and M_D are equal to the masses of the nucleon and deuteron, respectively, G^s_{EN} and G^s_{MN} denote the isoscalar form factors of the nucleon, while the constant Γ is determined by the condition $G^d_c(0)=1$. Going over in (1)–(3) to the nonrelativistic limit, we can obtain a representation similar to (1) for the nonrelativistic G^d_c.

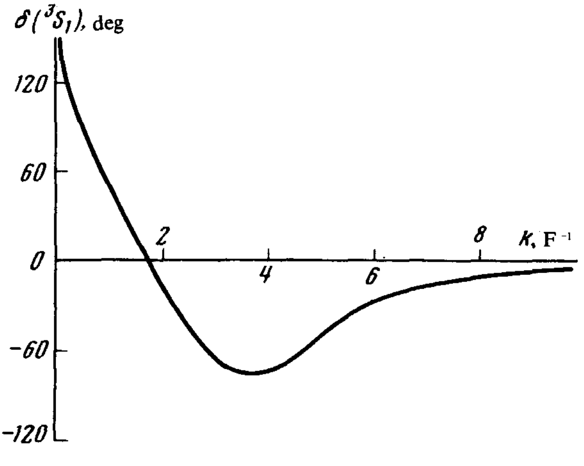

FIG. 1. Set of $^3S_1$ phase shifts used in the calculation of the form factors.

In the numerical calculations of the form factors we used the dipole approximation for G_{Ep} and the scaling relations for G_{Mp} and G_{Mn}. The form factor G_{En} is assumed equal to zero. The $^3S_1$ phases in (2) were chosen at $k < 2.2$ F^{-1} from the phase-shift-analysis data.[5] At $k > 2.2$ F^{-1}, the available phase-shift analysis data have low accuracy.[6] For k ranging from 4.2 to 11.7 F^{-1} we therefore used the results of the high-energy amplitude Regge analysis which are available for this region.[7] The $^3S_1$ phases separated by us by means of the Regge amplitudes are shown in Fig. 1. In the intermediate k region, the phases were joined together to satisfy continuity.

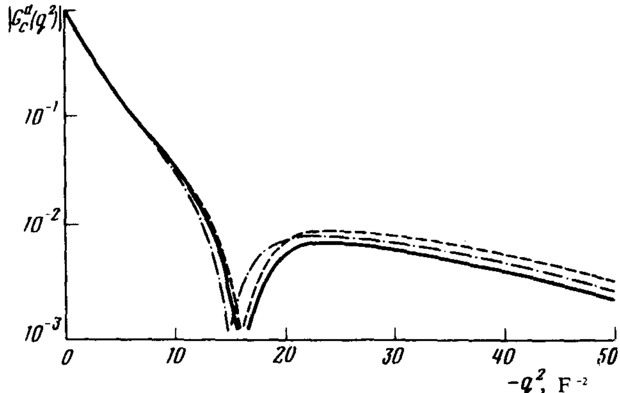

FIG. 2. Results obtained for the relativistic (dashed line) and nonrelativistic (solid line) form factors. A plot of the nonrelativistic form factor G_c^d, corresponding to a Reid potential with soft core (dashed-dot line) is shown for comparison.

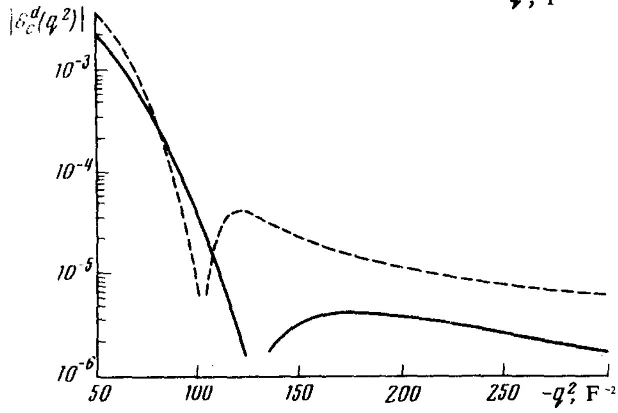

FIG. 3. The designations are the same as in Fig. 2.

The results of the form factors are shown in Fig. 2 and Fig. 3. The possible change of these results due to allowance for the admixture of the D wave were estimated by us with the aid of the McGee wave functions and do not exceed 15% for q^2 up to 300 F^{-2}. Some change in G_c^d due to allowance for unphysical cuts, whose contribution was discarded in the derivation of (1), is also insignificant.[8]

Thus, at large q^2 the relativistic corrections lead to a substantial change of G_c^d in magnitude and shift the positions of its "dips." It is important that this conclusion is made by us on the basis of a full allowance for the relativistic corrections in all orders in q^2/M^2, in contrast to the papers by Gross (see, e.g.,[9]), where the relativistic corrections were taken into account only in first order in q^2/M^2 (it would therefore be of interest to compare the results presented here with the calculations made, likewise in all orders in q^2/M^2, on the basis of the relativistic formalism of invariant wave functions, proposed in[10,11]). In the region $0 \leqslant q^2 \leqslant 30$ F^{-2} of small momentum transfers our results are similar to the results of Gross. The presented calculations show also that the relativistic corrections due to the presence in (3) of a term proportional to G^s_{MN} (and of purely relativistic origin) are small in the entire region of q^2. That is to say, we can neglect the relativistic spin-flip effect.

A complete two-channel relativistic calculation of both the charge and the magnetic and quadrupole form factors is based on a scheme similar to that given above (and will be published in succeeding papers). It is useful that the results obtained here for the charge form factor G^d_c can already be of interest in themselves if experimental information is available on the polarization of elastic *ed* scattering.

[1]R.G. Arnold *et al.*, Phys. Rev. Lett. **35**, 776 (1975).
[2]Yu.M. Shirokov, Nucl. Phys. B **6**, 158 (1968).
[3]A.I. Kirillov, V.E. Troĭtskiĭ, S.V. Trubnikov, and Yu.M. Shirokov, Fiz. Élem. Chastits At. Yadra **6**, 3 (1975) [Sov. J. Part. Nucl. **6**, 1 (1975)].
[4]V.I. Kukulin, V.E. Troitski, Yu.M. Shirokov, and S.V. Trubnikov, Phys. Lett. B **39**, 319 (1972).
[5]M.H. MacGregor *et al.*, Phys. Rev. **182**, 1714 (1969).
[6]N. Hoshizaki *et al.*, Prog. Theor. Phys. **45**, 1123 (1971).
[7]D. Austin *et al.*, Phys. Rev. D **2**, 2613 (1970).
[8]A.I. Kirillov and V.E. Troĭtskii, Yad. Fiz. **25**, 288 (1977) [Sov. J. Nucl. Phys. **25**, 157 (1977)].
[9]D. Gross, Phys. Rev. **142**, 1025 (1966).
[10]I.S. Shapiro, Pis'ma Zh. Eksp. Teor. Fiz. **18**, 650 (1973) [JETP Lett. **18** 380 (1973)].
[11]V.A. Karmanov, Pis'ma Zh. Eksp. Teor. Fiz. **23**, 62 (1976) [JETP Lett. **23**, 54 (1976)].