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THE PROTON ELECTROMAGNETIC FORM FACTOR AND HEAVY HYPOTHETICAL PARTICLES

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Электромагнитный формфактор протона и тяжелые гипотетические частицы

Проанализированы экспериментальные данные по упругому e–p рассеянию. Найдены простые полюсные параметризации формфакторов, позволяющие описать все известные данные. Обсуждается вопрос о возможном влиянии на формфактор гипотетического тяжелого глюона.

Препринт Объединенного института ядерных исследований.
Дубна, 1974

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Kazarinov Yu.M., Lapidus L.I.

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The Proton Electromagnetic Form Factor and Heavy Hypothetical Particles

The experimental data on e–p elastic scattering have been analyzed. Simple pole parametrizations of form factors have been found which make it possible to fit all the data available. A possible influence of the hypothetical gluon on the form factor is discussed.

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This note presents the results of analysis of all the published data on electron-proton elastic scattering. The analysis started in papers /1–3/ is now continued.

The lab.system differential cross section is as follows:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \cos^2\frac{\theta}{2}}{4E^2 \sin^4\frac{\theta}{2}\left(1 + \frac{2E}{M}\sin^2\frac{\theta}{2}\right)} \times$$

$$\times \left[\frac{G_E^2 + \frac{q^2}{4M^2} G_M^2}{1 + \frac{q^2}{4M^2}} + 2\,\mathrm{tg}^2\frac{\theta}{2}\, \frac{q^2}{4M^2} G_M^2 \right]. \qquad (1)$$

Here E is the energy of incident electrons, θ is the scattering angle, q^2 the transferred momentum squared, $G_M(q^2)$ and $G_E(q^2)$ the magnetic and electric proton form factors. In parametrizing the form factors we are based on the dispersion approach. From dispersion relations in the vector dominance approximation it follows that form factors are represented by a sum of pole terms, the appropriate poles being equal to the vector-meson masses. When the known vector mesons involving ρ' -meson are taken into account one cannot fit the data on electron-proton elastic scattering satisfactorily /4/. In paper /2/ it has been shown that the data on e – p scattering can be described if for the form factor G_M/μ (μ the proton magnetic moment) one takes the following expression:

$$\frac{1}{\mu} G_M = \frac{a_3}{1+a_1 q^2} + \frac{1-a_3}{1+a_2 q^2}, \qquad (2)$$

where all the quantities a_i are fitted parameters. Note that eq. (2) is a natural generalization of the known dipole formula

$$G_D(q^2) = \left(\frac{1}{1+\frac{q^2}{0.71}}\right)^2, \qquad (3)$$

which approximates $\frac{1}{\mu} G_M(q^2)$ well in the range of small q^2 ($q^2 < 1 (\mathrm{GeV}/c)^2$).

Recently the final data of the SLAC group[5] have been published on the e–p elastic scattering in a large interval of q^2 – from 1 to 25 $(\mathrm{GeV}/c)^2$. We will present the results of analysis of all e–p data involving the latter ones. For the form factor $\frac{1}{\mu} G_M$ we will adopt the parametrization (2). Also we will assume that the form factors $G_M(q^2)$ and $G_E(q^2)$ are connected by the scaling relation:

$$G_M(q^2) = \mu G_E(q^2). \qquad (4)$$

By making use of the same method as in papers[1,2] we obtain the following values for parameters:

$$a_1 = 0.71 \pm 0.02 \ (\mathrm{GeV}/c)^{-2}$$

$$a_2 = 2.15 \pm 0.06 \ (\mathrm{GeV}/c)^{-2} \qquad (5)$$

$$a_3 = -0.51 \pm 0.05 .$$

Here $\frac{\chi^2}{\bar{\chi}^2} = \frac{400}{320}$. From (5) we have

$$\left(\frac{1}{a_1}\right)^{1/2} = 1.19 \pm 0.02 \ \mathrm{GeV} \quad \left(\frac{1}{a_2}\right)^{1/2} = 0.68 \pm 0.01 \ \mathrm{GeV}. \qquad (6)$$

Thus, one of the poles of eq. (2) is close to the value of the ρ'-meson mass, the second to that of the ρ-meson mass.

When the parameters a_i were defined, normalization factors [1,2] (fitted parameters) were inserted into the functional χ^2. These factors are connected with the possible systematic errors*.

We have separately examined also the data of paper[5]. This analysis provides the following values of the parameters:

$$a_1 = 0.81 \pm 0.07 \ (\mathrm{GeV}/c)^{-2}$$

$$a_2 = 2.08 \pm 0.14 (\mathrm{GeV}/c)^{-2} \qquad (7)$$

$$a_3 = -0.65 \pm 0.17 .$$

Next, we rewrite eq. (2) in the following way:

$$\frac{1}{\mu} G_M = \frac{1-aq^2}{(1+a_1 q^2)(1+a_2 q^2)}, \qquad (8)$$

where

$$a = a_3 a_2 + (1-a_3) a_1 . \qquad (9)$$

From (5) we get

$$a = 0.02 \pm 0.02 \left(\frac{\mathrm{GeV}}{c}\right)^{-2}. \qquad (10)$$

The parameter a is small. If, however, one puts in (8) the parameter a equal zero then a satisfactory description of the data can be achieved only for $q^2 \le 5 (\mathrm{GeV}/c)^2$. The parameter a is necessary to give correctly the behaviour of form factor in the region of large q^2. The question naturally arises whether the term $(1-aq^2)$ of exp. (8) is

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* The values found for the normalization factors are the same as in ref.[2].

a result of an expansion in q^2 of the following expression

$$\frac{1}{1+aq^2}. \tag{11}$$

From (10) we find that $(\frac{1}{a})^{1/2}$ = 7 ±4 GeV. That the factor corresponding to a particle with large mass must be included into the nucleon form factor was discussed in paper /6/ and recently in paper /7/ . In ref. /6/ the corresponsing parameter is connected with the heavy photon discussed in paper /8/. In paper /7/ the parameter $(1/a)^{1/2}$ is interpreted as the mass of a heavy (~ 10GeV) particle sticking together partons within a nucleon (gluon).

We have analyzed all the data on e–p elastic scattering taking for the form factor the following expression:

$$\frac{1}{\mu} G_M(q^2) = \frac{1}{(1+b_1q^2)(1+b_2q^2)(1+bq^2)}. \tag{12}$$

At $\frac{\chi^2}{\overline{\chi^2}} = \frac{384}{320}$ the parameters b_i are found to be:

$$b_1 = 0.61 \pm 0.03\ (GeV/c)^{-2}$$

$$b_2 = 2.31 \pm 0.06\ (GeV/c)^{-2} \tag{13}$$

$$b = 0.04 \pm 0.004\ (GeV/c)^{-2}.$$

The corresponding "masses" are equal to:

$$(\frac{1}{b})^{1/2} = 1.28 \pm 0.03\ GeV$$

$$(\frac{1}{b})^{1/2} = 0.67 \pm 0.01\ GeV \tag{14}$$

$$(\frac{1}{b})^{1/2} = 5.00 \pm 0.22\ GeV.$$

Analysing the data of ref. /5/ we get

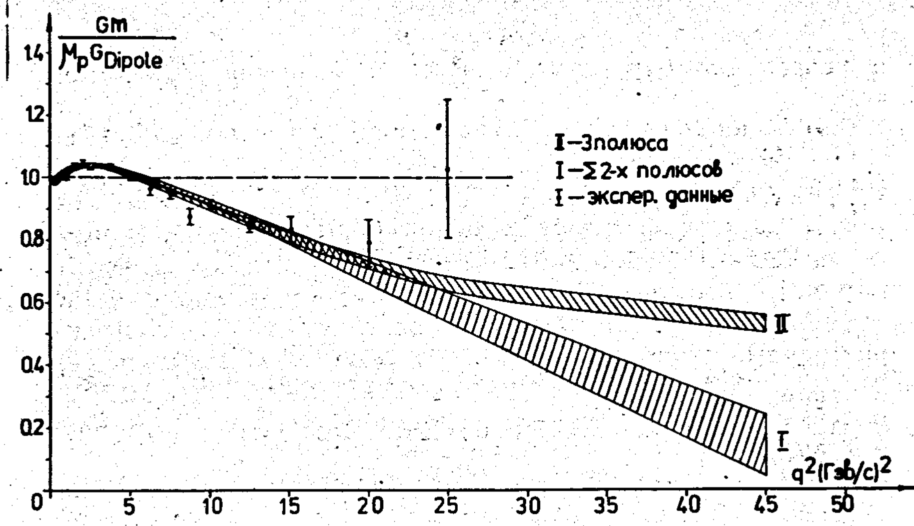

Fig. 1

$$b_1 = 0.65 \pm 0.07\ (GeV/c)^{-2}$$

$$b_2 = 2.33 \pm 0.15\ (GeV/c)^{-2} \tag{15}$$

$$b = 0.04 \pm 0.01\ (GeV/c)^{-2}.$$

In Fig. 1 the functions $\frac{G_M(q^2)}{\mu G_D(q^2)}$ are plotted for the two form factor parametrizations we have considered. The curve I ((II)) corresponds to eq. (2) (eq. (12)). As is seen from Fig. 1 the curves differ only in the region of $q^2 \geq 20\ (GeV/c)^2$. Thus, the analysis performed indicates that the important problems, raised in papers /6,7/, about the influence of heavy hypothetical particles (heavy photons, gluons) on the proton electromagnetic form factor require studying of the e–p elastic scattering at large momentum transfers. Note, however, that the data available do not contradict the hypothesis on the existence of such particles.

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