Electromagnetic form factor of the proton and heavy hypothetical particles

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The experimental data on elastic ep scattering are analyzed. Simple pole parametrizations of the form factors are obtained and make it possible to describe all the known data. The possible influence of a hypothetical gluon on the form factor is discussed.

We report here the results of an analysis of all the published data on elastic scattering of electrons by protons. We have continued the analysis initiated in[1–3].

The differential ep-scattering cross section in the lab system is

$$\frac{d\sigma}{d\Omega}=\frac{\alpha^2\cos^2\frac{\theta}{2}}{4E^2\sin^4\theta/2}\left(\frac{1}{1+\frac{2E}{M}\sin^2\frac{\theta}{2}}\right)\left[\frac{G_E^2+\frac{q^2}{4M^2}G_M^2}{1+\frac{q^2}{4M^2}}+2\operatorname{tg}^2\frac{\theta}{2}\cdot\frac{q^2}{4M^2}G_M^2\right]. \quad (1)$$

Here E is the energy of the initial electrons, θ is the scattering angle, q^2 is the square of the momentum transfer, and $G_M(q^2)$ and $G_E(q^2)$ are the magnetic and electric form factors of the proton. In the parametrization of the form factors, we base ourselves on the dispersion approach. From the dispersion relations in the vector-dominance approximation it follows that the form factors are represented by a sum of pole terms, and the corresponding poles are equal to the masses of the vector mesons. This does not make it possible to describe satisfactorily the data on the elastic scattering of electrons by nucleons in the case when known vector mesons, including the ρ' meson, are taken into account.[4] It was shown in[2] that the data on ep scattering can be described by assuming for the form factor G_M/μ (μ is the magnetic moment of the proton) the expression

$$\frac{1}{\mu}G_M(q^2)=\frac{a_3}{1+a_1q^2}+\frac{1-a_3}{1+a_2q^2}, \quad (2)$$

where all the α_i are variable parameters. We note that expression (2) is a natural generalization of the well-known dipole formula

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

which approximates $(1/\mu)G_M(q^2)$ adequately in the region of small q^2 [$q^2\lesssim 0.5$ (GeV/c)^2].

The SLAC group has recently published[5] correct data on ep scattering in a wide range of q^2 from 1 to 25 (GeV/c)^2. We present the results of an analysis of all the ep data, including these latest data. We assume the parametrization (2) for the form factor G_M/μ. We also assume that the form factors $G_M(q^2)$ are connected by the scaling relation

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

Using the same method as in[1,2] we get

$$a_1=0.71\pm0.02\ (\text{GeV}/c)^{-2},$$
$$a_2=2.15\pm0.06\ (\text{GeV}/c)^{-2}, \quad (5)$$
$$a_3=-0.51\pm0.05.$$

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

$$\left(\frac{1}{a_1}\right)^{1/2}=1.19\pm0.02\ (\text{GeV}/c);$$
$$\left(\frac{1}{a_2}\right)^{1/2}=0.68\pm0.01\ (\text{GeV}/c). \quad (6)$$

Thus, one pole of (2) is close to the value of ρ'-meson mass, and the other to that of the ρ meson.

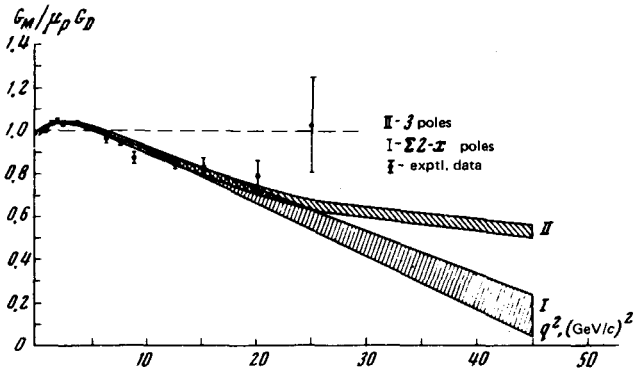
In the determination of the parameters α_i, normalization factors (variable parameters) connected with possible systematic errors[1)] were introduced[1,2] in the functional χ^2. We have also analyzed separately the data of[5]. For the parameters α_i we then obtain the values ($\chi^2/\overline{\chi^2}=20/11$)

$$a_1=0.81\pm0.07\ (\text{GeV}/c)^{-2},$$
$$a_2=2.08\pm0.14\ (\text{GeV}/c)^{-2}, \quad (7)$$
$$a_3=-0.65\pm0.17.$$

We rewrite expression (2) in the form

$$\frac{1}{\mu}G_M(q^2)=\frac{1-aq^2}{(1+a_1q^2)(1+a_2q^2)}, \quad (8)$$

where



Magnetic form factor of the proton with the error corridor, obtained from an analysis of all the available experimental data on ep scattering. Curves I and II correspond respectively to parametrizations (2) and (12). The points correspond to the experimental data from[5].

$$a = a_3 a_2 + (1 - a_3)a_1. \tag{9}$$

From (5) we get

$$a = 0.02 \pm 0.02\,(\mathrm{GeV}/c)^{-2}. \tag{10}$$

The parameter α is small. However, if we set α in (8) equal to zero, then a satisfactory description of the data can be obtained only in the region $q^2 \lesssim 5\,(\mathrm{GeV}/c)^{-2}$. The parameter α is essential to account correctly for the behavior of the form factor in the region of large q^2. This raises the question whether the term $(1 - \alpha q^2)$ in (8) is the result of an expansion, of the expression

$$\frac{1}{1 + \alpha q^2}\,, \tag{11}$$

in terms of q^2. From (10) we get $(1/\alpha)^{1/2} = 7 \pm 4$. The need for introducing into the form factor of the nucleon a factor that corresponds to a large-mass particle was discussed in[6] and recently in[7]. In[6] the corresponding parameter is related to the mass of the heavy photon discussed in[8]. In[7] the parameter $(1/\alpha)^{1/2}$ is interpreted as the mass of a heavy (≈ 10 GeV) particle that binds the partons in the nucleon (gluon).

We have analyzed all the data on elastic scattering of electrons by nucleons, assuming for the form factor the expression

$$\frac{1}{\mu} G_M(q^2) = [(1 + b_1 q^2)(1 + b_2 q^2)(1 + b q^2)]^{-1}. \tag{12}$$

At $\chi^2/\overline{\chi^2} = 384/320$ we obtain for the parameters b_i the values

$$b_1 = 0.61 \pm 0.3\,(\mathrm{GeV}/c)^{-2},$$
$$b_2 = 2.31 \pm 0.06\,(\mathrm{GeV}/c)^{-2}, \tag{13}$$
$$b = 0.04 \pm 0.004\,(\mathrm{GeV}/c)^{-2}.$$

The corresponding "masses" are

$$(b_1)^{-1/2} = 1.28 \pm 0.03\,(\mathrm{GeV}/c),$$
$$(b_2)^{-1/2} = 0.67 \pm 0.01\,(\mathrm{GeV}/c), \tag{14}$$
$$(b)^{-1/2} = 5.00 \pm 0.22\,(\mathrm{GeV}/c).$$

From an analysis of the data of[5] we obtain at $\chi^2/\overline{\chi^2} = 11/11$

$$b_1 = 0.65 \pm 0.07\,(\mathrm{GeV}/c)^{-2},$$
$$b_2 = 2.33 \pm 0.15\,(\mathrm{GeV}/c)^{-2}, \tag{15}$$
$$b = 0.04 \pm 0.01\,(\mathrm{GeV}/c)^{-2}.$$

The figure shows plots of the function $G_M(q^2)/\mu G_D(q^2)$ at the two form-factor parametrizations considered by us. Curves I and II correspond to expressions (2) and (12), respectively. As seen from the figures the curves differ only in the region $q^2 \gtrsim 20(\mathrm{GeV}/c)^2$. Our analysis shows therefore that the important questions raised in[6,7], concerning the influence exerted on the behavior of the electromagnetic form factors of the proton by heavy hypothetical particles (heavy photon, gluon), call for the study of elastic scattering of electrons by protons at large momentum transfers. We note, however, that these data do not contradict the hypothesis that such particles exist.

[1)]The obtained renormalization factors hardly differ from the values given in[2].

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