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Electromagnetic Structure of Nucleon

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In this note we present a simple model for the nucleon electromagnetic form factor, which has a form similar to the pion form factor derived by H. Sugawara,[1] who used a spurion formalism in applying the Veneziano formula to the vertex. The model surprisingly well reproduces the experimental data known up to date. The spurion technique results in a form factor with the recent attempts of similar approach,[2),3),4)] where an infinite series of poles is summed up in quite an intuitive way.

The spurion formalism[1] suggests that the form factor should have a form $\Gamma(1-\alpha)/\Gamma(n-\alpha)$ accompanied with possible satellite terms. Here α is a vector meson trajectory with appropriate quantum numbers, i.e. the ρ trajectory for the isovector part and the ω and ϕ trajectories for the isoscalar part. The guiding principles in this note to build up the model are i) the simplicity, ii) the super-convergence and iii) to satisfy the requirements imposed by the experiment at low energy limit. The requirements are[5]

$$\begin{aligned} &G_E{}^V(0)=0.5\,, \quad &&G_E{}^S(0)=0.5\,,\\ &G_M{}^V(0)=2.35\,, \quad &&G_M{}^S(0)=0.44\,,\\ &\dot{G}_E{}^V(0)=1.724\,, \quad &&\dot{G}_E{}^S(0)=1.226\,,\\ &\dot{G}_M{}^V(0)=6.725\,, \quad &&\dot{G}_M{}^S(0)=1.185\,, \end{aligned} \tag{1}$$

where $G(t)$ is Sachs' electric or magnetic form factor as an analytic function of t, the momentum transfer squared in unit of $(\mathrm{GeV}/c)^2$. The superscript indicates the isospin structure of the form factor. $\dot{G}$ is the derivative of G with respect to t.

We choose $n=3$ so that $G(t)$ behaves like t^{-2} in a large momentum transfer region, and we take account of only leading terms for ω and ϕ contributions, while we retain the first satellite term as well as the leading one for ρ. For the trajectory functions we simply assume

$$\alpha_\rho(t)=\alpha_\omega(t)=0.5+t\,, \quad \alpha_\phi(t)=t\,. \tag{2}$$

Thus our form factors contain eight free parameters as a whole, which can be fixed by imposing the condition (1).

The results are given explicitly by

$$\begin{aligned} G_E{}^V(t)&=\frac{0.558}{(0.5-t)(1.5-t)}-\frac{0.917}{(1.5-t)(2.5-t)}\,,\\ G_E{}^S(t)&=\frac{0.338}{(0.5-t)(1.5-t)}+\frac{0.184}{(1-t)(2-t)}\,,\\ G_M{}^V(t)&=\frac{2.010}{(0.5-t)(1.5-t)}-\frac{1.234}{(1.5-t)(2.5-t)}\,,\\ G_M{}^S(t)&=\frac{0.337}{(0.5-t)(1.5-t)}-\frac{0.020}{(1-t)(2-t)}\,. \end{aligned} \tag{3}$$

The proton and the neutron form factors corresponding to those of Eq. (3) are figured out in Figs. 1∼5, with the experimental data[5] available up to date. The fit is surprisingly good.

In conclusion several points should be remarked. 1) $G_E^{V,S}$ should be equal to $G_M^{V,S}$ at $t=4m_N^2$ to make Dirac and Pauli form factors free of singularity at the point. The condition is not satisfied strictly by the form factor (3). It is, however, to be noted that quite a bit of the second satellite terms, for example, is sufficient to retrieve the difficulty. 2) Though we assume (2) for simplicity, the predicted lower value (707 MeV) of the ρ meson mass is rather essential to obtain the nice fit. G_M^P, for example, may be even negative in the large momentum transfer region, say above 10 $(\mathrm{GeV}/c)^2$, if we use a trajectory which corresponds to the empirical ρ meson mass. This shift of the ρ pole may be attributed to the finite width of the resonance. 3) The only experimental measurement[6] in the time-like region is an upper limit for the cross section of the annihilation process $p+\bar{p}\rightarrow e^+ + e^-$ at $t=6.8$, which gives a value of $G_M^P \lesssim 0.12$. We predict $G_M^P = 0.017$ at the point. 4) Our model predicts odd daughters for all the vector mesons ρ, ω and ϕ. For example, the existence of these daughters has to be confirmed by the colliding e^+e^- experiment.

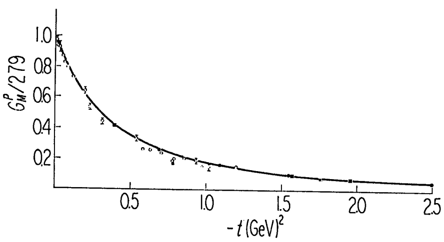

Fig. 1. $G_M^P/2.79$ up to $t=2.5(\mathrm{GeV}/c)^2$. The experimental data are those which are cited in reference 5).

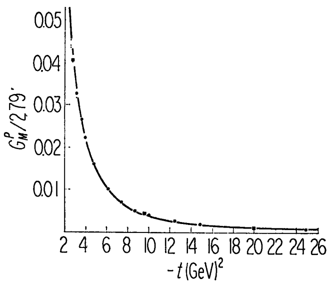

Fig. 2. $G_M^P/2.79$ up to $t=26(\mathrm{GeV}/c)^2$. For experimental data see the remarks on Fig. 1.

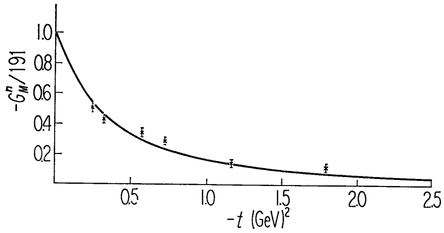

Fig. 3. $-G_M^n/1.91$ up to $t=2.5(\mathrm{GeV}/c)^2$. For experimental data see the remarks on Fig. 1.

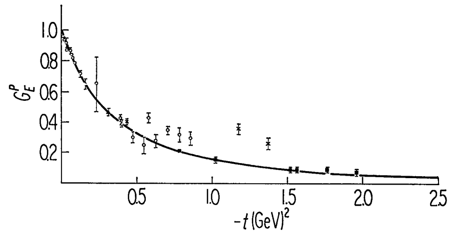

Fig. 4. G_E^P up to $t=2.5(\mathrm{GeV}/c)^2$. For experimental data see the remarks on Fig. 1.

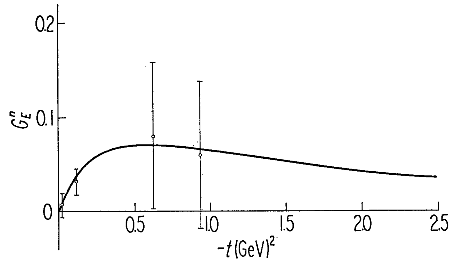

Fig. 5. G_E^n up to $t=2.5(\mathrm{GeV}/c)^2$. For experimental data see the remarks on Fig. 1.

1) H. Sugawara, preprint.
2) P. H. Frampton, Illinois preprint.
3) R. Jengo and E. Remiddi, CERN preprint.
4) P. diVecchia and F. Drago, Frascati preprint.

5) The experimental data quoted here are those which are cited in V. Wataghin, Nucl. Phys. **B10** (1969), 107.
6) B. Barish, D. Fong, R. Gomez, D. Hartill, J. Pine, A. V. Tollestrup, A. Maschke and T. F. Zipf, *Proceedings of the Conference on High Energy Two-Body Reactions, Stony Brook, 1966*.
M. Conversi, T. Massam, T. H. Muller and A. Zichichi, Nuovo Cim. **40** (1965), 690.