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Present Status of Meson Theory

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Meson theory, which had started as a field theory of nuclear forces more than twenty years ago, has had to live a hard life. The discovery of μ-mesons in cosmic rays, which occurred ten years earlier than the discovery of π-mesons, both stimulated and confused subsequent developments of meson theory. Although ~~μ-mes~~ the existence of the μ-meson remains to be one of the most puzzling things in Nature up till now, the π-meson theory of nuclear forces has begun to be recognized as more effective than expected a few years ago. This was mainly due to elaboration by groups of theoretical physicists who did not fail to consider carefully ~~the~~ both the merits and limitations of the theory in its present form.

Now meson theory of nuclear forces deals with the virtual π-mesons. If we start from a system which consists of two bare ~~π~~ nucleons, each interacting with a common π-meson field, then we have to discriminate between the virtual π-mesons which exist already in one-nucleon system and those which are characteristic to the two-nucleon system. The ~~latter~~ former contributes to the self-energy of ~~the~~ each ~~nucleon~~ of the nucleons isolated

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from each other, while the latter in general, gives rise to ~~the~~ an extra energy which depends on ~~relative positi~~ distance, relative velocity, spins, isospins of the nucleons and which can be interpreted as a nuclear potential, ~~at least~~, ~~However~~, ~~we have to recognize~~ t between two physical nucleons rather than bare nucleons. However, neither it is a simple procedure to separate two kinds of virtual mesons, nor the extra energy thus obtained ~~could be interpretated~~ ~~as satisfies the conditions~~ ~~qualifies~~ ~~alway~~ is ~~alway~~ qualified as a potential without reserve. The stagnation for many year in meson theory of nuclear forces could be attributed to the ~~failure to reconcile two extreme view points~~: belief in the possibility ~~it~~ of deriving ~~a nuclear potential whi~~ in a ~~systematic~~ sweeping manner a nuclear potential which makes sense even for ~~a~~ very short distances between nucleons, distances much shorter than the meson Compton wave-length. The failure in this undertaking lead many of ~~us~~ theoretical physicists to a too pessimistic attitude towards meson theory.

On the other hand, ~~since~~ the amount of information relating to real mesons in cosmic rays and those created by accelerators has be rapidly increasing ~~since~~ during these ten years or so. Here, too, theoretical physicists had to meet an obstacle in applying meson theory.

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Namely, the results of simple-minded perturbation calculations turned out to be, in many case, in poor agreement with experiments, in spite of the ~~situation that~~ fact that ~~all of the~~ qualitative predictions of meson theory were confirmed by experiments one after another during this period. Again many of theoretical physicists were discouraged in continuing troublesome calculations relating ~~real meson~~ to real meson processes.

The stagnation, ~~however~~, did not last forever. New hopes ~~appeared to~~ came out both in meson theory of nuclear forces and in the theory of real meson processes. Namely, the new method ~~approach to~~ initiated by Taketani about ten years ago ~~for~~ the ~~method of~~ derivation of nuclear potential ~~based on the limited~~ by a through an appropriately restricted use of perturbation calculation in meson theory has began to bear fruits in the meantime,(1) while the static theory initiated by Chew ~~in 1954~~ a few years ago(2) was successful in dealing with nuclear processes in which real mesons participate, such as p-wave scattering of mesons by nucleons. It was heartening that the effective coupling constant f^2 ~~α~~ between the nucleon ~~pseudoscalar~~ vector and the pseudoscalar meson turn out to have the same numerical

(1) See summary reports by Taketani and many others in Sup. Prog. Theor. Phys. 3, Nr. 3 (1956).

(2) Chew,

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value $g^2/\hbar c = 0.08$ both in the meson theory of nuclear forces and in the static theory of meson-nucleon scattering.

Appendix 1

Main Consequences at Intermediate energies (20 MeV ~ 150 MeV)

for nucleon-nucleon scattering

i) strong LS coupling is unnecessary
ii) static pion-theoretical potential can reproduce almost all existing data up to 150 MeV.

c.f. J. Iwadare, Recent Work done in Japan on the Two-Nucleon Interaction
(Report at the Conference on Nuclear Forces and the Few-Nucleon Problem, London, July 1959)

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Appendix 2

Main Results ~~of H~~ obtained by Japanese Group with Respect to Nuclear Potential

1. ~~Fundamental~~ π-N Interaction

$$\frac{g}{\mu}\int \rho(r)\tau_\alpha \sigma\cdot\nabla\varphi_\alpha(r)\,dr$$

derived from either

$$iG\int \bar{\psi}\tau_\alpha\gamma_5\varphi_\alpha\psi\,dr$$

static appr. → $$\frac{G}{2M}\int \rho_1(r)\tau_\alpha\sigma\cdot\nabla\varphi_\alpha\,dr+\frac{G^2}{2M}\int\rho_2(r)\varphi_\alpha^2\,dr$$

or

$$i\frac{g}{\mu}\int\bar{\psi}\tau_\alpha\gamma_5\gamma_\mu\psi\frac{\partial\varphi_\alpha}{\partial x_\mu}\,dr-\frac{g^2}{2\mu^2}\sum_\alpha\left[\int\bar{\psi}\tau_\alpha\gamma_5\gamma_\mu\psi\, n_\mu\,dr\right]^2$$

static appr. → $$\frac{g}{\mu}\int\rho_3(r)\tau_\alpha\sigma\cdot\nabla\varphi_\alpha\,dr$$

2. One-Pion-Exchange Potential

$$V^{(2)}(x)\sim\frac{1}{3}\left(\frac{g_e^2}{4\pi}\right)\mu c^2(\tau_1\tau_2)\left\{(\sigma_1\sigma_2)+S_{12}\left(1+\frac{3}{x}+\frac{3}{x^2}\right)\right\}\times e^{-x}/x$$

$x=\cancel{\mu}\,\kappa r$ $\qquad \kappa=\mu c/\hbar$

$\mu=273\,m_e$ $\qquad 1/\kappa=1.4\times10^{-13}$ cm

$\mu : M_p\sim 1:6.7$

$$S_{12}=3\frac{(\sigma_1 r)(\sigma_2 r)}{r^2}-(\sigma_1\sigma_2)$$

3. FST-Potential

source function $C(k)=\exp[-k^2/2k_{max}^2]$

$k_{max}=6\mu$

$g_e^2/4\pi=0.08$

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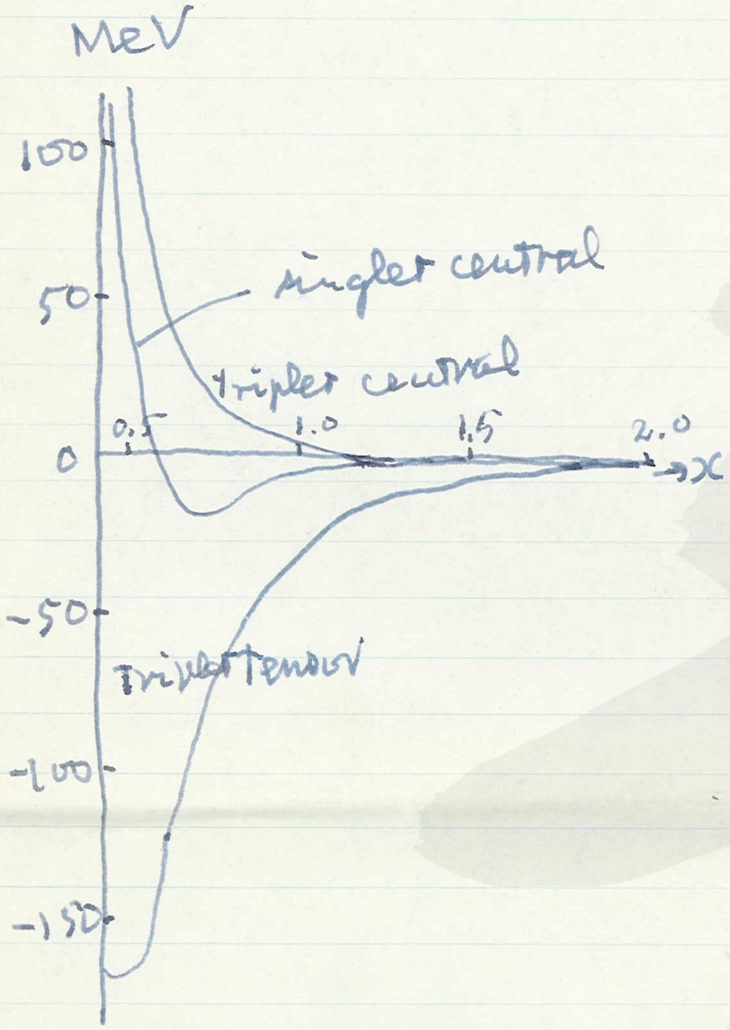
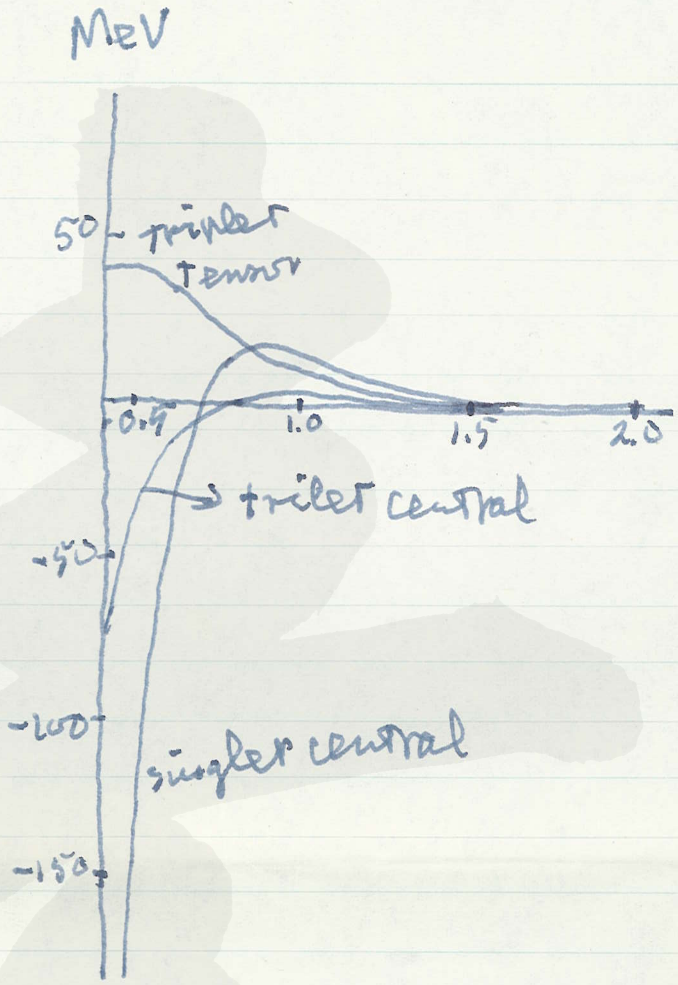


FST Even State Potential



FST Odd State Potential

Region I. classical $x \gtrsim 1.5$

II. dynamical $1.5 \gtrsim x \gtrsim 0.7$

III. phenomenological $0.7 \gtrsim x$

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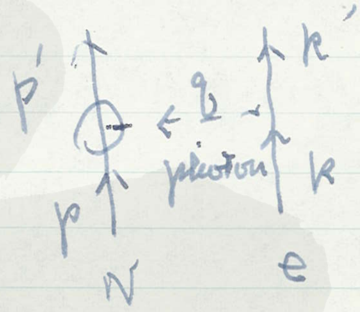
Appendix 3.

Analysis of Electromagnetic Structure of the Nucleon based on Meson Theory

c.f. K. Hiida, N. Nakanishi, Y. Nogami and M. Uehara, to be published in P.T.P., 1959.



electron-nucleon scattering
transition matrix element

$$j_\mu^N(p',p)(1/q^2)j_\mu^e(k',k)$$

$$q^2 \equiv q_\mu q_\mu$$

$$j_\mu^e(k',k) = -ie\bar{u}^e(k')\gamma_\mu u^e(k)$$

$$j_\mu^N(p',p) = i\bar{u}(p')[\gamma_\mu F_e^N(q^2) - \sigma_{\mu\nu} q_\nu F_m^N(q^2)]u(p)$$

center of mass system

$$q_0 = 0$$

$$F_e^N(q^2) = \int dr\, f_c^N(r) e^{iqr}$$

$$F_m^N(q^2) = \int dr\, f_m^N(r) e^{iqr}$$

$$\begin{cases} F_c^p(0) = e, & F_c^n(0) = 0 \\ F_m^p(0) = \mu_p & F_m^n(0) = \mu_n \end{cases}$$

$$F_c^p(q^2) = e\left(1 - \frac{q^2}{6}\langle r^2\rangle_c^p + \dots\right)$$

$$F_c^n(q^2) = e\left(0 - \frac{q^2}{6}\langle r^2\rangle_c^n + \dots\right)$$

$$F_m^N(q^2) = \mu_N\left(1 - \frac{q^2}{6}\underbrace{\langle r^2\rangle_m^N}_{} + \dots\right)$$

---

c.f. Hofstadter et al., R.M.P. 30(1958), 482

$$\langle r^2\rangle_c^p \approx \langle r^2\rangle_m^p \approx \langle r^2\rangle_m^n \approx (0.8 \times 10^{-13}\,\mathrm{cm})^2$$

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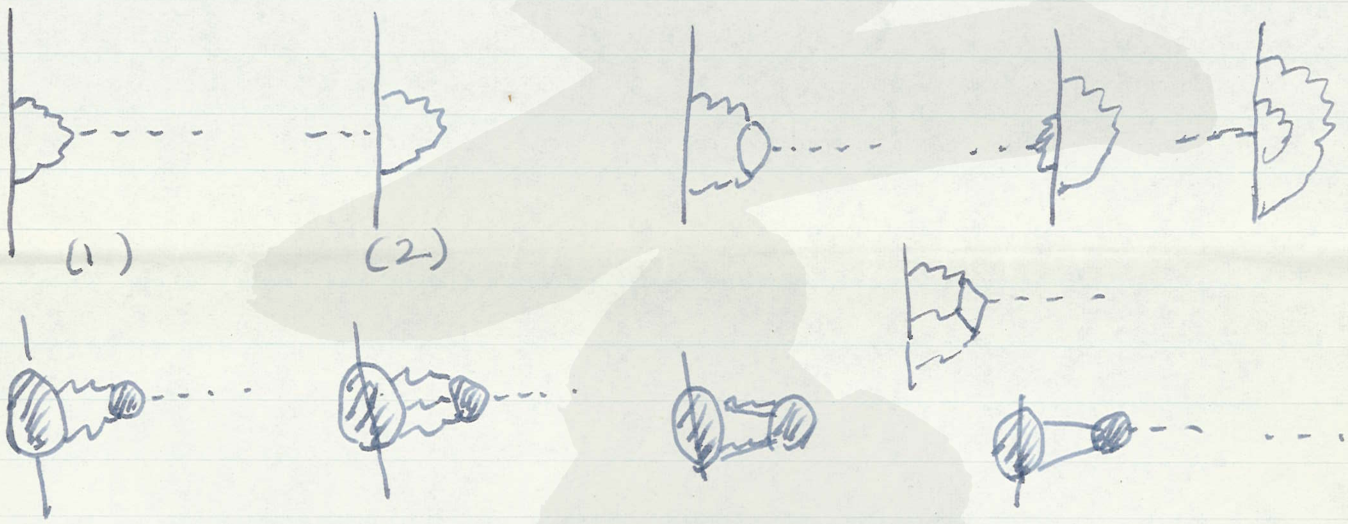
$\langle r^2\rangle_c^N \approx 0$ (for laboratory energy 100~650 MeV)

$F_c^N(q^2) = F_c^S(q^2) + \tau_3 F_c^V(q^2)$

$F_m^N(q^2) = F_m^S(q^2) + \tau_3 F_m^V(q^2)$

$\langle r^2\rangle_c^S \approx \langle r^2\rangle_c^V \approx \langle r^2\rangle_m^V \approx (0.8\times 10^{-13}\,\mathrm{cm})^2$

$\langle r^2\rangle_m^S \approx\ ?$



$2\pi\ (2m_\pi)$ $\quad 3\pi\ (3m_\pi)$ $\quad 2K\ (2m_K)$ $\quad N\bar{N}\ (2M)$ $\cdots$

$$F(q^2) = \int^\infty \frac{dm^2\, G(m^2)}{m^2+q^2}$$

$$f(r) = \int^\infty \frac{dm^2\, G(m^2)\, e^{-mr}}{4\pi r}$$

$$\left(\because \int \frac{dq\, e^{-iqr}}{m^2+q^2} = (2\pi)^3 \frac{e^{-mr}}{4\pi r}\right)$$

Perturbation calculations of graphs (1) and (2) gave reasonable values for μ_V, but gave much too large values for μ_S.

A. 3. 3.

i) Contribution of ... to distribution functions:

$$\langle r^2\rangle_c^V = (0.6\times10^{-13}\,\mathrm{cm})^2$$

$$\langle r^2\rangle_m^V = (0.5\times10^{-13}\,\mathrm{cm})^2$$

Corrections due to ... ... is small (multiple scattering π by N).
due to ... ... (meson structure)

N ⟶ NΣΛ

adds up together.

ii) contribution of to $\langle r^2\rangle^S_{c,m}$ of ---

$$\langle r^2\rangle_c^S \approx (1.3\times10^{-13}\,\mathrm{cm})^2$$

very large, but the contribution from Ξ almost cancel it, so that $\langle r^2\rangle_c^S$ could be smaller.

$$\mu^S\langle r^2\rangle_m^S \approx (1.4\times10^{-13}\,\mathrm{cm})^2$$

iii) Contribution to μ_S of $f(r)$ for very small r would be very important, so that we cannot analyse it on the basis of the present theory.

Thus, we can conclude that perhaps the main contributions to $\langle r^2\rangle^{V,S}_{c,m}$ for $r \gtrsim 1/3m_\pi$ come from graphs (2π) and (3π).
Anyway, the contribution of graph (3π) turned out to be unexpectedly large in such a way that the ~~puzzle result~~ experimental result $\langle r^2\rangle_c^S \approx \langle r^2\rangle_c^V$ would not be very puzzling ~~and~~. It seems that meson theory could be applied to the inner region as small as $r \gtrsim 1/3m_\pi$.

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