Feb 2003

Brief History of the Sakata Model and $U(3)$-Symmetry

– A Personal Recollection –

Y. Ohnuki
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1946∼1947: Rochester and Butler
Discovery of V-particles
(2 events in cloud chamber exp.)

$$\Downarrow$$

New particles:

$$\begin{cases} \text{Copious production,} \\ \text{Long life time} \sim 10^{-10} \text{ sec.} \end{cases}$$

1953:
Nakano-Nishijima and Gell-Mann Rule:

$$Q = T_3 + \frac{N_B + S}{2}$$

for strongly interacting particles (hadrons)

Q: charge in the unit of proton charge.
T_3: 3rd component of isospin [redacted].
N_B: baryon number.
S: strangeness (η-charge)

1955~1956:
S.Sakata:
On a Composite Model for the New Particles:
(delivered as an extra talk out of the program at the 10th annual meeting of Physical Society of Japan 9~16 Oct 1955 Tokyo, and published in Prog Theor Phys **16** (1956) 686.)

Fundamental Triplet:

$$\mathfrak{N} = (p, n),\ \Lambda, \qquad \overline{\mathfrak{N}} = (\overline{p}, \overline{n}),\ \overline{\Lambda}.$$

$$T_3 = \frac{N_p - N_n}{2}, \quad N_B = N_p + N_n + N_\Lambda, \quad S = -N_\Lambda$$

N-N-G relation: $Q = N_p$

Sakata stressed, in his paper, that the curious properties of the new particles could be reduced to those of Λ^0, just like the mysterious properties of the atomic nuclei were reduced to those of neutron. Hence our theory contains less arbitrary elements than was the case for original one of Nishijima and Gell-Mann.

* * * * *

Integral (half odd-integral) spin of nucleus

↕

Even (odd) atomic number,

The problem was solved by introducing the neutron as a constituent of nucleus. (Heisenberg, Iwanenko; 1932)

Analogy with atomic nuclei;

$$\begin{array}{ccc} \textit{nuclei} & \leftrightarrow & \textit{hadrons} \\ p & \leftrightarrow & \mathfrak{N}\ (=p,\, n) \\ n & \leftrightarrow & \Lambda \end{array}$$

Note:
Importance of the role of neutron in understanding the structure of nuclei was emphasized by Sakata in his graduation thesis *On the theory of nuclei* (in Japanese, Kyoto University 1933).

Calculation of masses of mesons in field theory

S.Tanaka, Prog. Theor. Phys. **16** (1956) 625.
Z. Maki, Prog. Theor. Phys. **16** (1956) 667.

1956: Matsumoto's mass formula for hadrons
(Prog.Theor.Phys.**16** (1956) 583.)

$$\begin{aligned} M = {} & 1840\times(N_N + N_{\overline{N}}) + 2180\times(N_\Lambda + N_{\overline{\Lambda}}) \\ & -3400\times(N_{N\overline{N}} - N_{NN} - N_{\overline{N}\,\overline{N}}) \\ & -3400\times(N_{N\overline{\Lambda}} + N_{\overline{N}\Lambda} - N_{N\Lambda} - N_{\overline{N}\,\overline{\Lambda}}) \\ & +250\times(N_{\Lambda\Lambda} + N_{\overline{\Lambda}\,\overline{\Lambda}}) \qquad \text{(Mev)} \end{aligned}$$

1958: Ogawa's Proposal:

Similar properties for the fundamental triplet

$$\begin{cases} \Delta N_p = \Delta N_n = \Delta N_\Lambda = 0 \text{ in strong int,} \\ \text{Spin of } p,\ n \text{ and } \Lambda = 1/2, \\ m_p \simeq m_n \simeq m_\Lambda \end{cases}$$

$$\Downarrow$$

Assumption for strong interaction:

$$\begin{cases} \text{Charge independece,} \\ \text{Invariance under } p \leftrightarrow \Lambda,\ n \leftrightarrow \Lambda. \end{cases}$$

Effective meson-baryon interaction:

$$\bar{\psi}(1)\boldsymbol{\tau}(1)\psi(1)\phi(1)$$

$$\psi(1) \equiv (p, n), \quad \phi(1) \equiv (\pi^+, \pi^0, \pi^-)$$

$$\Downarrow$$

$p \leftrightarrow \Lambda$ ↙

$$\bar{\psi}(2)\boldsymbol{\tau}(2)\psi(1)\phi(2)$$

$$\psi(2) \equiv (\Lambda, n),\ \phi(2) \equiv (\tilde{M}, M^0, M)$$

$n \leftrightarrow \Lambda$ ↘

$$\bar{\psi}(3)\boldsymbol{\tau}(3)\psi(3)\phi(1)$$

$$\psi(3) \equiv (p, \Lambda),\ \phi(3) \equiv (L, L^0, \tilde{L})$$

$M, L \quad \leftrightarrow \quad K^0, K^+$

iso-singlet meson $\leftrightarrow$ *linear comb of* M^0 *and* L^0

* * * * *

Ogawa's Fundamental Hamiltonian
(Dirac matrices omitted)

$$H' = \sum_{(i,j,k)} G\Big\{2\overline{N}_i N_j \overline{N}_j N_i + 2\overline{N}_j N_i \overline{N}_i N_j + (\overline{N}_k N_k)^2$$
$$-2\overline{N}_i N_i \overline{N}_j N_j + \varepsilon[(\overline{N}_k N_k)^2 + 2\overline{N}_i N_i \overline{N}_j N_j]\Big\},$$

$$(i, j, k) = (1, 2, 3) \quad cyclic.$$

$$N_1 = p, \quad N_2 = n, \quad N_3 = \Lambda.$$

$U(3)$ Symmetry:

$$\begin{cases} \vec{\tau}_{ab} \cdot \vec{\tau}_{cd} + \delta_{ab}\delta_{cd} = 2\delta_{ad}\delta_{cb}\,, \\ \text{Firez identities for } \gamma\text{-matrices} \end{cases}$$

$$\Downarrow$$

Charge independent 4-Fermion interaction

$$H' = \sum_A \left\{ g_A(\overline{\mathfrak{N}}\gamma_A\mathfrak{N})^2 + g'_A(\overline{\mathfrak{N}}\gamma_A\mathfrak{N})(\overline{\Lambda}\gamma_A\Lambda) + g''_A(\overline{\Lambda}\gamma_A\Lambda)^2 \right\},$$

$$\mathfrak{N} = (p,\, n), \quad \gamma_A = \gamma\text{-matrices.}$$

$$\Updownarrow$$

$$\textit{invariance under } p \leftrightarrow \Lambda,\ n \leftrightarrow \Lambda$$

$$\Downarrow$$

$$H' = \sum_A g_A(\overline{\chi}\gamma_A\chi)^2, \quad \chi = (p,\, n,\, \Lambda),$$

Invariant under $\chi' = U\chi$

(U: arbitrary 3×3 unitary matrix)

Thus

Ogawa's proposal $\Longleftrightarrow$ U_3-symmetry

in the limit of $m_p = m_n = m_\Lambda$.

Letters to Ogawa from Y.O. (1958)

(Sakata Memorial Archive)

- 29 Nov: Summary of some results obtained from U_3-symmetry and possible existence of $\pi^{0\prime}$
- 03 Dec: Derivation of octet ps-mesons of the same mass in the symmetry limit
- 06 Dec: Construction of the invariant operator (Casimir operator) and its eigen-value in 8-representation

In these letters the importance of group theoretical approach was emphasized, and it was mentioned that construction of a representation theory of $U(3)$ based on the Sakata model would be inevitable to make a systematic classification of composite particles.

Baryon classification:

1-baryon

$$\chi = p,\ n,\ \Lambda \in \underline{3}$$

2-baryon and 1-antibaryon

$$(\chi, \chi) \otimes \overline{\chi} : \quad \rightarrow \quad \underline{3} + \underline{15}$$

$$[\chi, \chi] \otimes \overline{\chi} : \quad \rightarrow \quad \underline{3} + \underline{6}^*$$

$(S,\ I) \in \underline{15}$:

$$(-2,\ 1/2),\ (-1,\ 0),\ (0,\ 1/2),\ (0,\ 3/2),\ (1,\ 1)$$

$(S,\ I) \in \underline{6}^*$: $\quad (-1,\ 1),\ (0,\ 1/2),\ (1,\ 0)$

$$\Downarrow$$

$$\Xi^0,\ \Xi^-,\ \text{and}\ \Delta(3,\ 3) \in \underline{15}$$

$$\Sigma^+,\ \Sigma^0,\ \Sigma^- \in \underline{6}^*,$$

B-S amplitudes

- (1-baryon, 1-antibaryon)-system

$$\varphi_{j\bar{k}}(x_1, x_2) = \langle 0|\, T\, \chi_j(x_1)\overline{\chi}_k(x_2)|B\rangle$$

- (2-baryon, 1-antibaryon)-system

$$\varphi_{jk\bar{l}}(x_1, x_2, x_3) = \langle 0|\, T\, \chi_j(x_1)\chi_k(x_2)\overline{\chi}_l(x_3)|B\rangle$$

$$\Vert$$

Irreducible Decomposition

$$\Downarrow$$

$$\underline{3} \times \underline{3}^* = \underline{1} + \underline{8}\,,$$

$$\underline{3} \times \underline{3} \times \underline{3}^* = \underline{3} + \underline{3} + \underline{6}^* + \underline{1}5$$

1959:

In June, M. Ikeda (Institute of Theoretical Physics, Hiroshima Univ) joined in with us.

*   *   *   *   *

Y. Ohnuki, M. Ikeda and S. Ogawa:
A Possible Symmetry in Sakata's Model for Bosons-Baryons System,
Contributed paper to the 9th Annual Int'l. Conf. on High Energy Physics, Kiev 1959 (unpublished).

M. Ikeda, S. Ogawa and Y. Ohnuki:
A Possible Symmetry in Sakata's Model for Bosons-Baryons System,
Prog. Theor. Phys. **22** (1959) 715; **23** (1960) 715.

Y. Yamaguchi:
A Composite Theory of Elementary Particles,
Prog. Theor. Phys. Suppl. No.11 (1959) 1.

J. Wess:
Investigation of the Invariance Group in the Three Fundamental Fields Model.
Nuovo Cimento **XI** (1959) 52.

Possibility of octet baryons:

Letter to S.Sakata from Y.Yamaguchi (CERN, 25 Dec 1959: unpublished) (Sakata Memorial Archive)

$$\begin{cases} \Sigma^+ = e^+\nu\lambda, & \Lambda = \dfrac{1}{\sqrt{6}}(\overline{\nu}\nu + e^+e^- - 2\mu^+\mu^-)\lambda\,, \\ p = \mu^+\nu\lambda, & \Xi^0 = \mu^-e^+\lambda\,, \quad . \quad . \quad . \end{cases}$$

*   *   *   *

$$\pi^+ = \lambda\overline{\lambda}e^+\nu, \quad K^+ = \lambda\overline{\lambda}\mu^+\nu\,, \quad . \quad . \quad .$$

Analysis of hadron resonances:

S. Sawada and M. Yonezawa (1960)

Ps-octet:

Odd parity of K-meson (1960)

Discovery of $\eta^0 (= \pi^{0\prime})$ (1961)

Proposal of vector-octet:

Salam and Ward:

Vector Fields Associated with the Theory of the Sakata Model, Nuovo Cim **XI** (1961) 568.

$$\rho^{0,\pm}, \quad (\omega^0,\ K^{*0},\ \overline{K^{*0}},\ K^{*\pm})$$

Developments (Eight-Fold Way)

Y. Ne'eman:

Derivation of Strong Interactions from a Gauge Invariance, Nucl Phys **26** (1961) 222

Gell-Mann:

Symmetries of Baryons and Mesons, Phys Rev **125** (1962) 1067

$\Downarrow$

Discovery of Ω^- (1686 $\pm$ 12 Mev, 1964)

$\Downarrow$

Quarks

(Gell-Mann, Zweig: 1964)

$\Downarrow$

$SU(6)$, $\widetilde{U}(12)$, $\cdots$.

Kiev (1959) Conf.
へ出した時の copy

A possible symmetry in Sakata's Model
for Boson-Baryon system

Y. Ohnuki (Nagoya University)
M. Ikeda and S. Ogawa (Hiroshima University)

In Sakata's model of strongly interacting particles, there are assumed proton p, neutron n and Λ -particle Λ to be the basic particles which compose other baryons. The strong interaction is characterized by the following selection rule

$$\Delta N_p = \Delta N_n = \Delta N_\Lambda = 0 \tag{A}$$

From this relation and from the similarity of the nature of these three particles, we are tempted to regard of these particles as standing on an equal footing. In fact, when the mass difference is neglected and the electromagnetic interaction is switched off, we could not expect any difference among three particles. Thus we can reasonably expect that a certain symmetry is also realized in their mutual interaction.

We propose, here, a frame work which explicitely assures the equivalence of three particles in the limiting case of zero mass difference. This means that our theory holds the invariance under the exchange of Λ -particle and proton or Λ -particle and neutron in addition to the usual charge independence and the conservation of hyperonic and electrical charge.

Notice that our statement on the nature of particle state, e.g. spin, parity and iso-spin <u>except mass</u> (or energy level), still holds with the finite mass difference between Λ and nucleon, when the actual case is attained by adiabatically increasing the mass of Λ from the original one (equal to nucleon mass) to the actual one.

Now we can easily verify that the above mentioned symmetry are equivalent to the invariance of the theory under the transformation of the 3-dimensional unitary group denoted by

$$\chi_\alpha \rightarrow \sum_{\beta=1,2,3} u_{\alpha\beta}\chi_\beta \quad \text{and} \quad \sum_{\beta=1,2,3} u^*_{\alpha\beta} u_{\beta\gamma} = \delta_{\alpha\gamma} \tag{1}$$

Science Press (Beijing)

Particle Physics and Introduction to Field Theory

粒子物理和场论简引

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chur london new york

Soon after, Gell-Mann and Ne'eman* took the decisive step of identifying the physical baryons p, n, Λ, Σ and Ξ, also, as members of an SU_3-octet. At that time the basic triplet was regarded more as a mathematical device for the construction of the octet (called the eightfold way) and the decuplet representations, which can then be directly applied to the observed hadrons. These applications of SU_3-symmetry led to great success in bringing order to the complex problems of spectroscopy, dynamics and decay rates of hadrons.

We now know that all hadrons can be viewed as composites of quarks**. In this chapter, we consider only the three low-lying quark fields: up, down and strange, which are sometimes referred to as different "flavors". Each will be represented by an element of the column matrix

$$q = \begin{pmatrix} q^1 \\ q^2 \\ q^3 \end{pmatrix} . \tag{12.1}$$

The strong interaction is assumed to be approximately invariant under the transformation

$$q \to vq \tag{12.2}$$

where v is unitary. The detailed form of the strong interaction will be considered later when we discuss quantum chromodynamics in Chapter 18. Here we examine only the consequences of the symmetry assumption.

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* M. Gell-Mann, Phys.Rev. 125, 1067 (1962); Caltech Report CTSL-20 (1961); Y. Ne'eman, Nucl.Phys. 26, 222 (1961).

** G. Zweig, CERN report (unpublished); M. Gell-Mann, Phys.Lett. 8, 214 (1964).

Chapter 12

SU_3 SYMMETRY

That the strong interaction may have a much wider internal symmetry than the U_2 group was first considered by Sakata *, who explored the possibility of SU_3 symmetry generated by the unitary transformations between p, n and Λ. However, Sakata's approach encountered serious difficulties, since the Λ-nucleon force turns out to be quite different from the nucleon-nucleon force. Major progress was made by Y. Ohnuki ** in 1960 who avoided the dynamical difficulties of the Sakata model; instead he put the emphasis on the kinematics of SU_3. The observed hadrons are regarded as composites of a triplet of "baryon" fields, called χ_1, χ_2 and χ_3 by Ohnuki. These fields have the same quantum numbers as p, n and Λ, but their quanta differ from the physical baryons because of some unspecified dynamical bound-state mechanism. By examining various representations of the SU_3 group, Ohnuki was able to identify the physical pions and kaons as members of an SU_3 octet, thereby predicting a new pseudoscalar meson, which was later discovered and is now called η^o.

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* S. Sakata, Progr.Theoret.Phys. 16, 686 (1956).

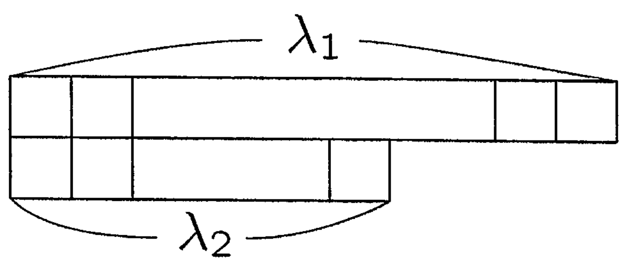
** Y. Ohnuki, Proceedings of the International High-energy Conference, CERN (1960), p. 843.

Generalized Bargmann-Wigner Equation:

Amplitude, $\psi_{s_1 s_2 \cdots s_n}(x)$.

s_A $(A = 1, 2 \cdots, n)$; Dirac spinor indices.

We symmetrize them with the Young diagram



where $\lambda_1 \geq \lambda_2 \geq 0$ and $\lambda_1 + \lambda_2 = n$.
The generalized B-W amplitude:

$$\psi_{(\lambda_1,\lambda_2):s_1 \ldots s_n}(x), \text{ or simply } \psi_{(\lambda_1,\lambda_2)}(x),$$

which is assumed to satisfy

$$(\gamma^A_\mu \partial_\mu + m)\, \psi_{(\lambda_1,\lambda_2)}(x) = 0,$$

$$(m \neq 0, \quad A = 1, 2, \ldots, n).$$

γ^A_μ; γ-matrices acting on the A-th Dirac indices s_A of the amplitude.
The above set of simultaneous equations (generalized B-W equation) are known to describe a particle of mass m and spin $(\lambda_1 - \lambda_2)/2$.

Quantized B-W Fields:

$$\overline{\psi}_{(\lambda_1,\lambda_2)}(x) = \psi^\dagger_{(\lambda_1,\lambda_2)}(x) \prod_{A=1}^{n} \gamma_4^A$$

Commutators:

$$[\psi_{(\lambda_1,\lambda_2);\, s_1\dots s_n}(x),\ \overline{\psi}_{(\lambda_1,\lambda_2);\, s'_1\dots s'_n}(y)]_\mp$$
$$= iN\Big\{(\lambda_1,\ \lambda_2) : \prod_{A=1}^{n} (m - \gamma_\mu \partial_\mu)_{s_A s'_A}\Big\} \Delta(x-y),$$

$$\left\{ \begin{array}{l} \text{upper sign} \\ \text{lower sign} \end{array} \right. \sim \left\{ \begin{array}{l} \text{bose; } (n = even) \\ \text{fermi; } (n = odd) \end{array} \right. .$$

$$\Big\{(\lambda_1,\ \lambda_2) : X_{s_1\dots s_n}\Big\};$$

$(\lambda_1,\ \lambda_2)$-symmetrization with respect to $s_1 \dots s_n$

Current:

$$J_\mu(x) = iN' \sum_{A=1}^{n} [\overline{\psi}_{(\lambda_1,\lambda_2)}(x),\ \gamma_\mu^A \psi_{(\lambda_1,\lambda_2)}(x)]_\pm$$

Energy-Momentum Tensor:

$$\theta_{\mu\nu}(x) = \frac{-N'}{4} \sum_{A=1}^{n} \Big\{ [\overline{\psi}_{(\lambda_1,\lambda_2)}(x),\ \gamma_\mu^A \overleftrightarrow{\partial}_\nu \psi_{(\lambda_1,\lambda_2)}(x)]_\pm + [\overline{\psi}_{(\lambda_1,\lambda_2)}(x),\ \gamma_\nu^A \overleftrightarrow{\partial}_\mu \psi_{(\lambda_1,\lambda_2)}(x)]_\pm \Big\}$$

S. Sakata (1911~1970), Photo 1960

Progress of Theoretical Physics, Vol. 16, No. 6, December 1956

On a Composite Model for the New Particles*

Shoichi Sakata

Institute for Theoretical Physics, Nagoya University, Nagoya

September 3, 1956

Recently, Nishijima-Gell-Mann's rule[1] for the systematization of new particles has achieved a great success to account for various facts obtained from the experiments with cosmic rays and with high energy accelerators. Nevertheless, it would be desirable from the theoretical standpoint to find out a more profound meaning hidden behind this rule. The purpose of this work is concerned with this point.

It seems to me that the present state of the theory of new particles is very similar to that of the atomic nuclei 25 years ago. At that time, we had known a beautiful relation between the spin and the mass number of the atomic nuclei. Namely, the spin of the nucleus is always integer if the mass number is even, whereas the former is always half integer if the latter is odd. But unfortunately we could not understand the profound meaning for this even-odd rule. This fact together with other mysterious properties of the atomic nuclei, for instance the beta disintegration in which the conservation of energy seemd to be invalid, led us to a very pessimistic view-point that the quantum theory would not be applicable in the domain of the atomic nucleus. However the situation was entirely changed after the discovery of the neutron. Iwanenko and Heisenberg[2] proposed immediately a new model for the atomic nuclei in which neutrons and protons are considered to be their constituents. By assuming that the neutron has the spin of one half, they explained the even-odd rule for the spins of atomic nuclei as the result of the addition law for the angular momenta of the constituents. Moreover, they could reduce all the mysterious properties of atomic nuclei to those of the neutron contained in them.

Supposing that the similar situation is realized at present, I proposed a compound hypothesis for new unstable particles to account for Nishijima-Gell-Mann's rule. In our model, the new particles are considered to be composed of four kinds of fundamental particles in the true sense, that is, nucleon, antinucleon, Λ^0 and anti-Λ^0. If we assume that Λ^0 has such intrinsic properties as were assigned by Nishijima and Gell-Mann, we can easily get their even-odd rule for the composite particles as the result of the addition laws for the ordinary spin, the isotopic spin and the strangeness. In the next table, the models and the properties of the new particles are shown together with those of the fundamental particles in the true sense.
Here $\mathfrak{N}$ and $\overline{\mathfrak{N}}$ denote nucleon and antinucleon respectively, whereas Λ and $\bar{\Lambda}$ denote Λ^0 and anti-Λ^0 respectively[3].

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* The content of this letter was read before the annual meeting of the Japanese Physical Society held in October 1955.

A note on the same supject has also been published in Bulletin de L'acadèmie Polonaise des Sciences (Cl. III-vol. IV, No. 6, 1956)

Name	Model	Isotopic Spin	Strangeness	Ordinary Spin
$\mathfrak{N}$		1/2	0	1/2
$\bar{\mathfrak{N}}$		1/2	0	1/2
Λ		0	-1	1/2?
$\bar{\Lambda}$		0	1	1/2?
π	$\mathfrak{N}+\bar{\mathfrak{N}}$	1	0	0
$\theta(\tau)$	$\mathfrak{N}+\bar{\Lambda}$	1/2	1	0?
$\bar{\theta}(\bar{\tau})$	$\bar{\mathfrak{N}}+\Lambda$	1/2	-1	0?
Σ	$\mathfrak{N}+\bar{\mathfrak{N}}+\Lambda$	1	-1	1/2?
Ξ	$\bar{\mathfrak{N}}+\Lambda+\Lambda$	1/2	-2	1/2?

So far as the internal structure is not concerned, our model for new particles is identical with that of Nishijima and Gell-Mann. However, it should be stressed that the curious properties of the new particles could be reduced to those of Λ^0, just like the mysterious properties of the atomic nuclei were reduced to those of neutron. Hence our theory contains less arbitrary elements: than was the case for original one of Nishijima and Gell-Mann.

Though the rigorous treatment of our model is a very hard task[4], it is worthwhile to notice that most of the composite particles which seem to be stable against the strong interaction can be identified with the well-known new particles, and that there are possibilities of predicting some more new particles which have not been discovered up till now.[5]

Finally, it should be remarked that there are some other arguments in favour of the compound hypothesis for the elementary particles. In spite of the great success achieved by the advent of Tomonaga-Schwinger's technique, it has recently become clear that we could not avoid the internal inconsistency of the quantum field theory, so far as the point model for elementary particles was adopted. Moreover, in the case of π-meson, the cut-off prescription has recently been proved to be very powerful in order to account for the experimental results. These facts indicate strongly the necessity of substantial innovations in the model for the elementary particles, though some change has already been made by the discovery of the renormalization technique. Landau pointed out that the model for the electron would possibly be changed by the effect of the gravitational field. But in the case of π-meson we must look for another effect, because the cut-off radius is found to be as large as the order of the nucleon Compton wave length in contrast to $e^2/mc^2 \cdot e^{-137} \sim 10^{-58}$ cm which appeared in the quantum electrodynamics.[6]

1) T. Nakano and K. Nishijima, Prog. Theor. Phys. **10** (1953), 581; K. Nishijima, Prog. Theor. Phys. **12** (1954), 107; **13** (1955), 285; M. Gell-Mann, Phys. Rev. **92** (1953), 833.

2) D. Iwanenko, Nature **129** (1932), 798; W. Heisenberg, ZS. Phys. **77** (1932), 1.

3) Markov (Rep. Acad. Sci. USSR, 1955) proposed also a composite model which is very similar to ours. It should be remarked that our model may be considered as a generalization of the π-meson model proposed by Fermi and Yang (Phys. Rev. **76** (1948), 1739), and that it will throw a new light on Heisenberg's

Fermi–Yang P.R. 76, 1739, 1949
Wentzel 79, 710, 1950

		Spin	Parity	Isospin	η	$\left(Q = I_z + \frac{\eta}{2}\right)$ $S = I_z + \frac{S}{2}$	
$\pi^{\pm,0}$	$= \begin{cases} P + \bar{N} \\ P + \bar{P} (N + \bar{N}) \\ N + \bar{P} \end{cases}$	0	−1	1	0	0	
	$N + \bar{N}$	0		0	0		
		1		1	0		
		1		0	0		0
$\theta^{+,0}$	$\begin{cases} P + \bar{V}^0 \\ N + \bar{V}^0 \end{cases}$	0	S_0 +1	$\frac{1}{2}$	1	1	0
$\tau^{+,0}$	$\begin{cases} P + \bar{V}^0 \\ N + \bar{V}^0 \end{cases}$	0	P_0 −1	$\frac{1}{2}$	1	1	0
N	P, N	$\frac{1}{2}$	A	$\frac{1}{2}$	1	0	1
$\bar{N}$	$\bar{N}, \bar{P}$	$\frac{1}{2}$	B	$\frac{1}{2}$	−1	0	−1
Λ^0 V^0	V^0	$\frac{1}{2}$	B	0	0	−1	+1
$\bar{\Lambda}^0$ $\bar{V}^0$	$\bar{V}^0$	$\frac{1}{2}$	A	0	0	+1	−1
Σ^{+0-}	$\begin{cases} P + \bar{N} + V^0 \\ P + \bar{P} + V^0 (N + \bar{N} + V^0) \\ N + \bar{P} + V^0 \end{cases}$	$\frac{1}{2}$	A	1 (2 1 0)	0		1
	$P + P + \bar{V}^0$	$\frac{1}{2}$		1 (2 1 −1 −2)	2		
Ξ $Y^{0,+}$	$P + P + \bar{N}$	$\frac{1}{2}$		$\frac{3}{2}$	+1	−2	1
	$\begin{cases} V^0 + V^0 + \bar{N} \\ V^0 + V^0 + \bar{P} \end{cases}$	$\frac{1}{2}$	$S_{\frac{1}{2}}$ B	$\frac{1}{2}$	−1		
X	$V^0 + V^0 + \bar{N}$		$P_{\frac{1}{2}}$ A				1

Fragment $\Sigma P + V$

Nucleus $\Sigma P + N$

		rel.	absolute	absolute	
strong	$(\tilde{N} \tilde{V} N V)$ $(\tilde{N} \tilde{N} N N)$ $(\tilde{V} \tilde{V} V V)$	$\Delta I = 0$ $\Delta \eta = 0$	$\Delta \xi = 0$	$\Delta Q = 0$	$\Delta S = 0$
weak	$(\tilde{N} \tilde{N} N V)$ $(\tilde{V} \tilde{V} N V)$	$\Delta I = \frac{1}{2}$ $\Delta \eta = \frac{1}{2}$			$\Delta S = 1$
forbiden	$\tilde{N} \tilde{N} V V$ ($N N$ $\tilde{V} \tilde{V}$)	$\Delta I = 1$ $\Delta \eta = 1$			$\Delta S = 2$

~~On the~~ A possible model for the new unstable particles.

仮定 I. 素粒子として
baryon ~~family~~ に P N V^0 の三種を仮定する.
lepton ~~family~~ に $e^{\pm}$, ν, $\mu^{\pm}$ を仮定する.

仮定 II
π-on family, baryon family, heavy fragment, nucleus は P, N, V^0 及その anti-particle の集合体としてみちびく.

仮定 III (P, N) は $(\frac{1}{2}, -\frac{1}{2})$ の τ-spin をもつ
V^0 は 0 の τ-spin をもつ
(但し spin は共に $\frac{1}{2}$)

仮定 IV (i) baryon の conservation と charge の Conserv.
(ii) Strong Interaction においては
$\Delta I = 0 \quad \Delta I_z = 0$
(iii) Weak Interaction では
$\Delta I = \frac{1}{2}$

$n = \xi$

$Q = I_z + \frac{n}{2} + \frac{S}{2}$
$= I_z + \xi I$

$\xi I = \frac{\xi}{2}(2+\xi S) \quad I = \xi S + 2$

S : Strange[ness]