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Reviewer: Yoshio Koide

Remarks on the Unified Model of Elementary Particles

by Z. Maki, M. Nakagawa and S. Sakata

Prog. Theor. Phys. Vol. 28 (1962) 870

PTP Highlights
PROGRESS OF THEORETICAL PHYSICS

The following eleven papers are among the most heavily-cited in history, and have been greatly influential in the development of physics during the last half century. These papers were selected from the archives of PTP by the Editorial Committee as representing the best works from a variety of fields.

- Tomonaga's First Paper among His Nobel Prize Winning Works on Renormalization

On a Relativistically Invariant Formulation of the Quantum Theory of ....

by S. Tomonaga

Prog. Theor. Phys. Vol. 1 (1946) 27

(中略)

- The First Paper Predicting Neutrino Mixing and Oscillation

Remarks on the Unified Model of Elementary Particles

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（理論物理学刊行会ホームページより）

Progress of Theoretical Physics, Vol. 28, No. 5, November 1962

Remarks on the Unified Model of Elementary Particles

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(Received June 25, 1962)

A particle mixture theory of neutrino is proposed assuming the existence of two kinds of neutrinos. Based on the neutrino-mixture theory, a possible unified model of elementary particles is constructed by generalizing the Sakata-Nagoya model.*) Our scheme gives a natural explanation of smallness of leptonic decay rate of hyperons as well as the subtle difference of G_v's between μ-e and β-decay.

Starting with this scheme, the possibility of K_{e3} mode with $\Delta S/\Delta Q=-1$ is also examined, and some bearings on the dynamical role of the B-matter, a fundamental constituent of baryons in the Nagoya model, are clarified.

§ 1. Introduction and summary

In recent years, a considerable progress has been made in accumulationg detailed knowledge on the structure of interaction of elementary particles. Various kinds of excited particles have been discovered in succession, and the systematization of them from a unified point of view turns out to be an urgent problem of particle physics. In this connection, we can expect that

Also note

Progress of Theoretical Physics, Vol. 28, No. 4, October 1962

Possible Unified Models of Elementary Particles with Two Neutrinos*)

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and
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(Received June 5, 1962)

Possible unified models of elementary particles are discussed assuming the existence of two kinds of neutrino accompanying with electron and muon respectively. The discussions are focused on the Nagoya model which is based on the Sakata model of baryons and mesons and the Gamba-Marshak-Okubo symmetry. In its connection the following assumptions are taken: i) Fundamental particles among baryons and mesons have one-to-one correspondence with leptons or their linear combinations. The correspondence is realized through a kind of "matter". ii) Basic leptons do not transmute each other by the strong interaction between the fundamental baryons.

Maki-Nakagawa-Sakata (June 25,1962)

を

Katayama-Matumoto-Tanaka-Yamada

(June 5, 1962)

と比較しながら，また，当時の物理の歴史的
状況も含めながら，紹介したい.

以下，前者をMNS，後者をKMTYと略記する.

Contents

1 Brief history to the modified Nagoya model

1956 Sakata model

S.Sakata, PTP 16 (1956) 686

ハドロンは (p, n, Λ)より作られる複合粒子である

メソン $S\bar{S}$ $3 \times 3^* = 1 + 8$

バリオン $SS\bar{S}$ $3 \times 3 \times 3^* = 3 + 3 + 6^* + 15$

c.f **1964 Quark model**

M.Gell-Mann, PL 8 (1964) 214

G.Zweig, CERN preprint 8419/TH 412 (1964)

1959 Baryon-Lepton symmetry

A.Gamba, R.E.Marshak and S.Okubo,
Proc.Natul.Acad.Sci. 45 (1959) 1274

$$
\begin{array}{ccc}
p & \leftrightarrow & \nu \\
n & \leftrightarrow & e \\
\Lambda & \leftrightarrow & \mu
\end{array}
$$

1960 Nagoya model

Z.Maki, M.Nakagawa, Y.Onuki and S.Sakata,
PTP 23 (1960) 1274

$$
\begin{aligned}
p &= \langle \nu \; B^{+} \rangle \\
n &= \langle e^{-} B^{+} \rangle \\
\Lambda &= \langle \mu^{-} B^{+} \rangle
\end{aligned}
$$

1962 Discovery of two neutrinos

G.Danby et al, PRL 9 (1962) 36

$\pi^{\pm} \to \mu^{\pm} + \bar{\nu}/\nu$ からのneutrinoを核子にぶつける

$\mu^{\pm}$ は生まれるが, $e^{\pm}$ は生まれない

1962 Modified Nagoya model

Y.Katayama, K.Matumoto, S.Tanaka, E.Yamada, PTP 28 (1962) 675;
Z.Maki, M.Nakagawa, S.Sakata, PTP 28 (1962) 870

$$p = \langle \nu_1 B^+ \rangle$$
$$n = \langle e^- B^+ \rangle$$
$$\Lambda = \langle \mu^- B^+ \rangle$$
$$p' = \langle \nu_2 B^+ \rangle$$

$$\nu_1 = \nu_e \cos\theta + \nu_\mu \sin\theta$$
$$\nu_2 = -\nu_e \sin\theta + \nu_\mu \cos\theta$$

2 Topics which we should notice

(1) How they understood the weak interaction?

1963 Cabibbo angle

1964 (1968) Salam, 1967 Weinberg

(2) Did they predict the 4th quark?

1964 Quark model

1970 GIM mechanism

1974 Discovery of charm

(3) Did they predict neutrino oscillation?

1998 Discovery of neutrino oscillation

3 How they understand the weak interactions?

- 観測事実:

$$J_{weak} = J(e \to \nu_e) + J(\mu \to \nu_\mu)$$
$$+ aJ(n \to p) + bJ(\Lambda \to p)$$

$$a \simeq 1, \quad b \simeq 0.2$$

- 1963 Cabibbo angle

N.Cabibbo, PRL 10 (1963) 531

$$a^2 + b^2 = 1$$

$$a = \cos\theta, \quad b = \sin\theta$$

1962

KMTY

$$\nu_1 = \frac{1}{\sqrt{1+s^2}}[e^0 + s\,\mu^0],$$

$$\nu_2 = \frac{1}{\sqrt{1+s^2}}[-se^0 + \mu^0];$$

MNS

$$\nu_1 = \nu_e \cos\delta + \nu_\mu \sin\delta,$$

$$\nu_2 = -\nu_e \sin\delta + \nu_\mu \cos\delta.$$

$$p = \langle B^+ \nu_1 \rangle, \quad n = \langle B^+ e^- \rangle, \quad \Lambda = \langle B^+ \mu^- \rangle,$$

$$J_\lambda = \langle j_\lambda \rangle_B = (\bar{n}p)_\lambda \cos\delta + (\bar{\Lambda}p)_\lambda \sin\delta.$$

Cabibbo の a, b は normalization factors,

これに対して, KMTY&MNS は

two families の概念に基づく "mixing"

How about neutral currents?

- KMTY

The weak current may be produced from the neutrino current

$$j_\lambda^0 = \bar{\nu}_a o_\lambda^+ \nu_a + \bar{\nu}_b o_\lambda^+ \nu_b. \qquad (2\cdot29)$$

After the attachment of *E*-matter, it becomes the charged current

$$j_\lambda = \bar{\nu}_a o_\lambda^+ \nu_a' + \bar{\nu}_b o_\lambda^+ \nu_b'$$

- MNS

neutral currents には全く言及無し

両者とも **SU(2)** の概念は全くなし！

参考:

1974 Neutral currents の発見

1961 Glashow, 1964 (1968) Salam, 1967 Weinberg

4 Did they predict the 4th quark?

1964 Quark model

M.Gell-Mann, PL 8 (1964) 214

G.Zweig, CERN preprint 8182/Th401 (1964)

1970 GIM mechanism

S.L.Glashow, J.Iliopoulos and L.Maiani, PRD 2 (1970) 1285

1974 Discovery of charm

J.J.Aubert et, al., PRL 33 (1974) 1404

J.-E.Augstin, et al., PRL 33 (1974) 1406

C.Bacci, et al., PRL 33 (1974) 1408

KMTY

2–A. Model without new baryon

To make a correspondence between four four-components leptons and three fundamental baryons in the Sakata model, one of the leptons should be sacrificed in the course of this connection. It means to assume that B^+-matter can not be attached or bound to one of neutrino or of their mixture states. We express this assumption as

$$p=\langle \nu_1 \ B^+\rangle,\ n=\langle e^- \ B^+\rangle,\ \Lambda=\langle \mu^- \ B^+\rangle,\ no=\langle \nu_2 \ B^+\rangle, \qquad (2\cdot 5)$$

where the additional assumption that the B^+-matter can be attached only to the one of the mixture states, not to the one of pure states, is made. For example,

2–B. Model with new baryon

If there are baryons corresponding to both of the neutrino mixture states, we have

$$p=\langle \nu_1 B^+\rangle,\ n=\langle e^- B^+\rangle,\ \Lambda=\langle \mu^- B^+\rangle,\ V=\langle \nu_2 B^+\rangle \qquad (2\cdot 10)$$

in place of the correspondence $(2\cdot 5)$. Here V is a newly introduced baryon, which has positive charge and is probably in iso-singlet state $(I=0)$. Unless

MNS

but one of the most simple models may be given *under the postulate that the true neutrinos should be so defined that B^+ can be bound to ν_1 to form a proton but cannot be bound to ν_2*, symbolically

$$p = \langle B^+ \nu_1 \rangle, \quad n = \langle B^+ e^- \rangle, \quad \Lambda = \langle B^+ \mu^- \rangle, \qquad (2\cdot5)$$

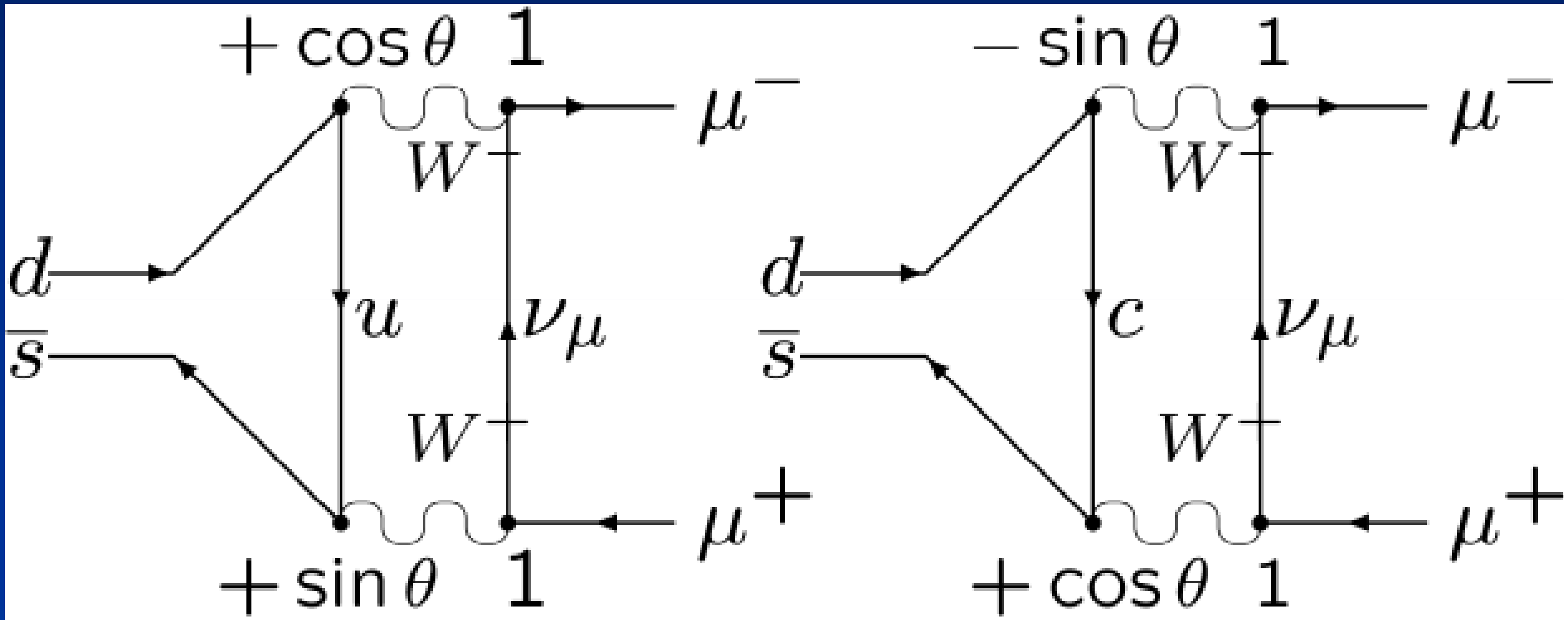
and $\langle B^+ \nu_2 \rangle$ corresponds no baryons.**) We call this correspondence *the modified B-L symmetry*. The baryonic weak current J_λ obtained from (2·1′) is written as

$$J_\lambda \equiv \langle j_\lambda \rangle_B = (\bar{n}p)_\lambda \cos\delta + (\bar{\Lambda}p)_\lambda \sin\delta. \qquad (2\cdot6)$$

**) Alternatively, we can assume that $\langle B^+ \nu_2 \rangle$ corresponds to a new kind of baryon with a very large mass.

GIM mechanism

Why is the observed $K_L \to \mu^+\mu^-$ decay so small?



$$u \leftrightarrow d' \equiv d\cos\theta + s\sin\theta$$

$$c \leftrightarrow s' \equiv -d\sin\theta + s\cos\theta$$

B.Richter の見解

1975年 基研にて

（C.C.Ting とともに，1976年度ノーベル物理学賞を受賞）

Modified Nagoya model: Beautiful
GIM Mechanism: Necessity

5 Did they predict neutrino oscillation?

- **KMTY**

Neutrino oscillation には言及なし

- **MNS**

In the present case, however, weak neutrinos are *not stable* due to the occurrence of a virtual transmutation $\nu_e \rightleftarrows \nu_\mu$ induced by the interaction (2·10). If the mass difference between ν_2 and ν_1, i.e. $|m_{\nu_2} - m_{\nu_1}| = m_{\nu_2}$*) is assumed to be a few Mev, the transmutation time $T(\nu_e \rightleftarrows \nu_\mu)$ becomes $\sim 10^{-18}$ sec for fast neutrinos with a momentum of $\sim$Bev/c. Therefore, a chain of reactions such as[10)]

$$\pi^+ \to \mu^+ + \nu_\mu, \tag{2·19a}$$

$$\nu_\mu + Z(\text{nucleus}) \to Z' + (\mu^- \text{ and/or } e^-) \tag{2·19b}$$

is useful to check the two-neutrino hypothesis only when $|m_{\nu_2} - m_{\nu_1}| \lesssim 10^{-6}$ Mev under a conventional geometry of experiments. Conversely, the absence of e^- in the reaction (2·19b) will be able not only to verify the two-neutrino hypothesis but also to provide an upper limit of the mass of the second neutrino (ν_2) if the present scheme should be accepted.

$$\mathcal{L}_{int} = [\,(\bar{\psi}_0 \Lambda \psi_0) + (\bar{\varphi}_0 \Lambda' \varphi_0)\,] X^* X \tag{2·10}$$

as an example. Here, Λ and Λ' are (2×2) matrices satisfying

$$\det \Lambda = \det \Lambda' = 0. \tag{2·11}$$

$$\mathcal{L}_{int} = \left[(\bar{\mu}_0 \ \bar{e}_0)\Lambda \begin{pmatrix} \mu_0 \\ e_0 \end{pmatrix} + (\bar{\nu}_{\mu 0} \ \bar{\nu}_{e0})\Lambda' \begin{pmatrix} \nu_{\mu 0} \\ \nu_{e0} \end{pmatrix} \right] X^* X$$

$$\mathcal{L}_{int} = [\,(\eta_1{}^2 + \eta_2{}^2)\,\bar{\mu}\mu + 2\eta'^2 \bar{\nu}_2 \nu_2\,] X^* X. \tag{2·10′}$$

MNSか？ PMNSか？

(1) B. Pontecorvo, JETP (USSR) 37, 1751 (1959)

MNSが引用

4) A prototype of two neutrino theory was first proposed by S. Sakata and T. Inoue (Prog. Theor. Phys. **1** (1946), 143). See also J. Schwinger, Ann. Phys. **2** (1957), 407.
K. Nishijima, Phys. Rev. **108** (1958), 907.
M. Konuma, Nucl. Phys. **5** (1958), 504.
I. Kawakami, Prog. Theor. Phys. **19** (1958), 459.
B. Pontecorvo, JETP (USSR) **37** (1959), 1751.
S. Oneda and J. C. Pati, Phys. Rev. Letters **2** (1959), 125.
T. D. Lee and C. N. Yang, Phys. Rev. **119** (1960), 1410.

（内容）How to test two neutrino hypothesis

(2) B. Pontecorvo, Zh. Eksp. Theor. Fiz. 33, 549 (1957); Sov. Phys. JETP 26, 984 (1968) (?)

牧二郎「ニュートリノ振動の予言と実証」（学術月報 1990 September, 961-966) が引用

（内容） neutrino-antineutrino oscillation

(3) B. Pontecorvo, Zh. Eksp. Theor. Fiz. 53, 1717 (1967); Sov. Phys. JETP 26, 984 (1968)

PDG06が引用

（内容）Solar neutrino problem の解釈として neutrino osc を議論

ニュートリノ振動公式をはじめて与えた論文

その他の予言

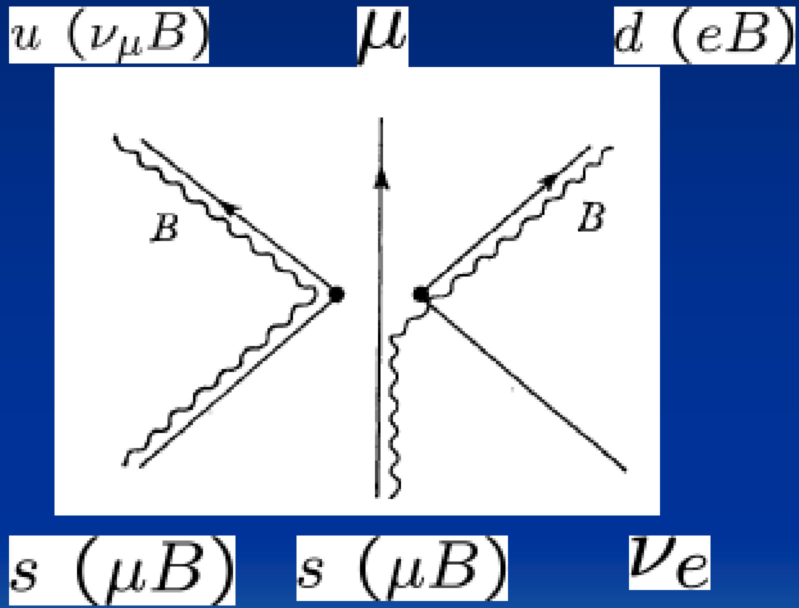
$\Delta S = 2$ Decay の予言　（MNS）

$$s + s \rightarrow d + u + \mu + \overline{\nu}_e$$

$$K^+ \rightarrow \overline{K}^0 + \mu^+ + \nu_e$$

$$\Xi^- \rightarrow n + \mu^- + \overline{\nu}_e,$$

$$\Xi^0 \rightarrow p + \mu^- + \overline{\nu}_e.$$



However, KMTY have commented:

interaction of baryons with $\Delta Q/\Delta S = 1/2$ together with $\Delta Q/\Delta S = -1$. Then it is a rather difficult problem to introduce such six-fermion interaction when there is no weak interaction with $|\Delta S| > 1$.

6 Summary and Conclusion

	KMTY	MNS
	June 5, 1962	June 25, 1962
Title:	Possible Unified Models of	Remarks on the Unified Model of
姿勢：	可能なmodels の長所・短所を比較検討	名古屋模型の1つの発展版を提唱
Cabibbo angle:	**mixing** として理解	**mixing** として理解
$SU(2)_L$:	なし	なし
Charm:	「あり」と「なし」に分けて	「なし」（ただし，脚注にコメント）
Nu-osc:	言及なし	$\nu_e \leftrightarrow \nu_\mu$ を予言
New fields:	**B and E**	**B and X**

教訓

- 新しいモノを導入したら，無理してその非観測性を論ずるより，まもなくそれが見える方に賭けるべき.
- 新しいモノの予言は，形の美しさからではなく，
  具体的必然性のもとに主張すべき.
- 「群」という考えは，どの時代の物理でも重要な手がかりを提供してくれる.

  (c.f.　1959 Ikeda-Ogawa-Ohnuki: U(3) model)
- 模型屋としては，いろいろな可能性を並べる百貨店方式より，特定のお勧め品を目玉とする専門店方式がよい.