Shoichi Sakata: His Life and Physics

—— *Collections of Materials in Sakata Memorial Archival Library* ——

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Shoichi Sakata and his Nagoya School made a lot of important achievements at the predawn of the particle physics revolution. The "two-meson" theory (introduction of the second generation leptons), the "C-meson theory" (a theory which inspired Tomonaga's renormalization theory), the "Sakata model" (a precursor to the quark model), and the "Maki-Nakagawa-Sakata" theory on the neutrino mixings are among them. These outputs are now regarded as essential ingredients in modern particle physics. Sakata also took his leadership in setting up democratic administration system in his theoretical particle physics group (E-ken). It was this democratic atmosphere in which many excellent physicists were brought up as Sakata's diciples. In this talk, I introduce Sakata and his achievements in physics, showing various materials archived in the Sakata Memorial Archival Library (SMAL), an archival repository of primary material showing Sakata's activities. These SMAL documents vividly show Sakata's way of thinking in his approach to the new physics.

§1. Introduction to SMAL

It is a great honor for me to be allowed to introduce Professor Shoichi Sakata and his physics achievements in his centennial symposium, as a person currently in charge of the Sakata Memorial Archival Library (SMAL). Professor Sakata is one of the scientific giants I continue to look up to. I need to confess, however, my knowledge on Professor Sakata was rather limited when I began to take care of SMAL in 2008. Actually, Sakata passed away in 1970, very long ago before I started my particle theory research as a graduate student in Nagoya in the late 1980s. Since 2008, I learned about him from the literature collected in Refs. 1)–3) and from the materials archived in the SMAL, and conversations with my elder colleagues. This year, I joined the publication committee of the "Shoichi Sakata Copenhagen Diary"[5)] and learned a lot about Sakata from the committee members including Professor T. Maskawa, Professor M. Kobayashi, Professor M. Konuma, Professor S. Kamefuchi, Professor Y. Ohnuki, Professor H. Obayashi, Professor S. Sawada, Professor A. I. Sanda, Professor K. Yamawaki, and Professor T. Nishitani, who recently published an excellent biography of Sakata.[4)] In this presentation, I concentrate on what I learned from the materials archived in the SMAL and from the scientific/historical papers written by Sakata and his Nagoya School members. Thanks to dedicated efforts of professors who took initiatives in the SMAL operation in the past, these materials, combined with the articles collected in Refs. 1)–3), vividly show Sakata's way of thinking in his approach to physics and research group administration.

Sakata Memorial Archival Library (SMAL) is a repository to archive various materials related with Sakata's achievements, including his research notebooks, scientific paper manuscripts/drafts, colloquium notes, letters and postcards. It has its origin when Department of Physics decided to preserve Sakata's former office (4th floor of the School of Science Building-B) in 1973, after the death of Sakata in 1970. The SMAL committee was then established in 1986 to keep Sakata's various materials in order to provide primary sources for researchers of the Japanese particle physics history. The SMAL was operated under supervision of the SMAL committee chaired by Professor S. Ogawa, Professor Y. Ohnuki, Professor M. Yasuno and then Professor M. Aramaki. Thanks to the dedicated efforts of Professor Ogawa, two volumes of catalogues of SMAL materials were published by the committee. The volume 1[6] was first published in 1989 and then revised in 1992, while the volume 2[7] was published in 1995. Recently these catalogues were digitized by T. Nishitani and it became possible to download them from the SMAL website. Although the SMAL committee was dissolved around 2000, SMAL has been maintained by continuous efforts of Professor A. I. Sanda, Professor K. Yamashita, Professor S. Sato, and Professor K. Yamawaki and other members of Department of Physics.

The SMAL was forced to move out from the Building-B due to its anti-quake reinforcement. It is now located at a corner of 2008 Nobel Prize Exhibition Gallery (2nd floor, ES-Building, Nagoya U.). Several research materials of Sakata are exhibited in the gallery.

§2. Sakata's achievements in physics

2.1. *Developments in Yukawa's meson theory*

After the graduation from Kyoto Imperial University in 1933, Sakata moved to Nishina Laboratory at Riken as a research associate. In collaboration with Y. Nishina and S. Tomonaga, he studied the electron pair creation process by gamma ray there. He then joined Yukawa's group at Osaka Imperial University in 1934 as an assistant and became the most important collaborator of Yukawa in the developments of his meson theory for the nuclear force. Immediately after the discovery of new particle in cosmic ray experiments, in 1937, Yukawa and Sakata wrote a paper examining the properties of the nuclear force potentials between protons and neutrons induced by the Yukawa meson exchanges.[8] This is the second paper in the series of developments of Yukawa's meson theory. Note also that, in their 1937 paper, Yukawa and Sakata discussed the potential between identical nucleons (such as n and n) as well as the potential between different nucleons (p and n). Through this analysis, they pointed out the possible existence of the neutral Yukawa meson particle (π^0). This is the point they made certainly going beyond Yukawa's first paper[9] which postulated the charged meson $\pi^{\pm}$ only. Sakata subsequently wrote an article in Japanese[10] concentrating on his analysis for the nuclear force potential between identical nucleons. A memo on his evaluation of the nuclear force between identical nucleons is archived in SMAL (37 01 ZC 01).

Yukawa and Sakata continued their research on meson theory with M. Taketani in their third paper,[11] and with M. Kobayashi and M. Taketani in their fourth paper.[12] In these works, Sakata evaluated the Yukawa meson lifetime assuming the

$\pi^- \to e^- + \bar{\nu}$ decay process. A memo on this calculation is archived in SMAL (38 01 ZC 02).

Sakata moved back to Kyoto Imperial University in 1940 with H. Yukawa. One of the most outstanding outputs from him in this year is the prediction of the π^0 decay into photons, $\pi^0 \to \gamma+\gamma$, $\pi^0 \to \gamma+\gamma+\gamma$, etc. Note that π^0 is the particle that Sakata first postulated in his 1937 paper with H. Yukawa.[8)] In collaboration with Y. Tanikawa,[13)] Sakata found the short lifetime of π^0, consistent with the failure of its experimental searches in the cosmic rays. Sakata and Tanikawa estimated its lifetime $\tau \sim 10^{-16}$ sec, which remarkably agrees with the correct value we now know $\tau \simeq 8.4 \times 10^{-17}$ sec.[*)]

Sakata continued to study the lifetime of the Yukawa meson. In his 1940 paper,[14)] he numerically estimated the decay lifetime of the Yukawa meson $\pi^+ \to e^+\nu$ and, assuming the original form of Yukawa's meson theory, he obtained the value $\tau \sim 10^{-8}$ sec,[**)] which was too short by a factor 10^{-2} in comparison with the lifetime of the new particle observed in cosmic ray experiments. Sakata pointed out two possibilities to remove this apparent discrepancy: (1) to assume existence of at least two kinds of Yukawa mesons as suggested by Møller, Rosenfeld, and Rozenthal,[15)] and (2) to abandon the original Yukawa meson model as the theory of β decay and to evaluate the loop diagram in the decay process $\pi^+ \to p + \bar{n} \to e^+ + \nu$. The first possibility can be regarded as the seed of the "two meson theory", while the second raised Sakata's later interests in the divergence problem in quantum field theories.

2.2. *Second generation leptons*

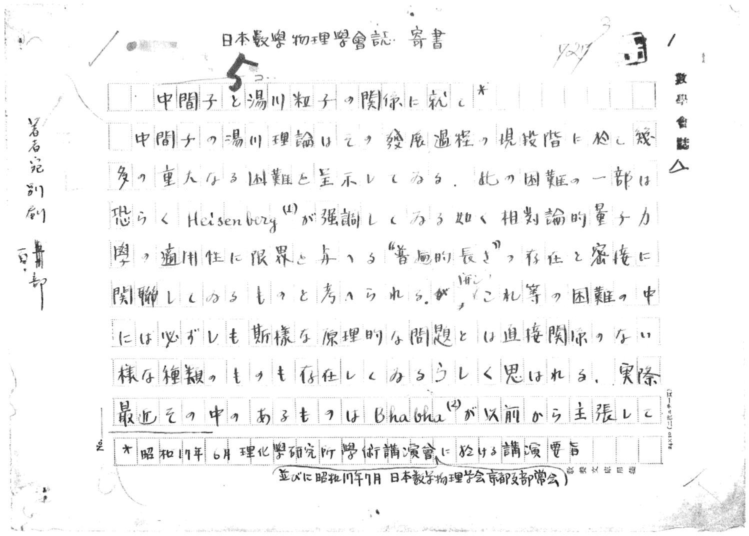
1942 became the memorial year for the second generation leptons (μ and ν_μ), when Sakata and Inoue advocated their "two-meson theory".[16)] At that time, a charged particle discovered in the hard component of cosmic rays was misidentified as Yukawa's meson (π, nuclear force career particle). The cross section of this particle with atmospheric nuclei was much smaller than the predicted value in Yukawa's meson theory. Moreover, the lifetime of the new particle discovered in the cosmic ray experiments was about 100 times longer than the Yukawa theory estimate. Sakata and Inoue solved this puzzle by introducing new charged and neutral fermions. We now know that these new particles correspond to the second generation leptons μ and ν_μ in the modern language. They then discussed the decay of Yukawa particle

$$\pi^+ \to \mu^+ + \nu_\mu,$$

and identified μ as the new particle discovered in the hard component of cosmic rays. Sakata, who was an expert of the $\pi^+ \to e^+ + \nu_e$ decay, certainly had an advantage

*) This remarkable agreement should be regarded as an accidental coincidence. In Ref. 13), Sakata and Tanikawa numerically evaluated the lifetime $\pi^0 \to \gamma + \gamma + \gamma$ in the vector mesotron theory, in which π^0 is assumed to be a spin-1 particle.

**) In its original form of Yukawa's meson theory, it was assumed that Yukawa meson π mediates not only the strong nuclear force but also the neutron β decay $n \to p+\pi^- \to p+e^- +\bar{\nu}$. In his 1940 paper, Sakata estimated the size of the $\pi e^-\bar{\nu}$ coupling strength from the lifetimes of light nuclei based on this (eventually failed) assumption. This is one of the reasons why he got the lifetime much shorter than our current knowledge $1/\Gamma(\pi^+ \to e^+\nu) \simeq 2.1 \times 10^{-4}$ sec.


日本數學物理學會誌 寄書

中間子と湯川粒子の関係に就て*

中間子の湯川理論はその發展過程の現段階に於て幾多の重大なる困難を呈示してゐる。此の困難の一部は恐らくHeisenberg(1)が強調してゐる如く相對論的量子力學の適用性に限界を與へる"普遍的長さ"の存在と密接に關聯してゐるものと考へられるが、これ等の困難の中には必ずしも斯様な原理的な問題とは直接関係のない様な種類のものも存在してゐるらしく思はれる。実際最近その中のあるものはBhabha(2)が以前から主張して

* 昭和17年6月理化學研究所學術講演會に於ける講演要旨（並びに昭和17年7月日本數学物理学会東部支部常会）

Fig. 1. Draft manuscript for the two-meson theory paper published in Phys.-Math. Soc. Jpn. on July 1942. (SMAL 42 01 WP 01)

in the calculation of this decay mode. This hypothesis, called "two meson theory", clearly explained the small cross section of the cosmic ray particle with atmospheric nuclei as well as its longer lifetime. Sakata and Inoue also discussed the decay process

$$\mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e.$$

They determined the μ coupling strength relevant for this decay process from the observed lifetime of the cosmic ray particle and found that it should be much smaller than the hadronic coupling strength.

An alternative scenario, in which μ was assumed to be a bosonic particle, was discussed by Y. Tanikawa and S. Nakamura at the same time.*) Unfortunately, due to the war circumstances, the English printing of Sakata-Inoue's two-meson theory paper was delayed until 1946,[18] one year before the "two-meson theory" of Marshak and Bethe[19] and the famous nuclear emulsion photographs catching $\pi \to \mu\nu$ taken by Powell's group in their cosmic ray experiment.[20]

2.3. *Renormalization of QFT*

In October 1942, Sakata moved to Department of Physics, Nagoya Imperial University**) as a full professor. At that time, Nagoya Imperial University was a newborn university established only three years before. The Department of Physics

*) Sakata wrote an article about his two-meson theory developments in Ref. 1), in which it was vividly described how Sakata got his idea of the two-meson theory with two fermionic daughter particles (μ and ν_μ), influenced by conversations with Tanikawa (bosonic version of two-meson theory) and the Møller-Rosenfeld theory.[15] It was unfortunate that Tanikawa and Nakamura did not write a scientific paper on their bosonic version two-meson theory in 1942. Tanikawa wrote a paper on this subject later in 1947,[17] in which he discussed $\pi \to \mu\gamma$ decay assuming bosonic μ.

**) Nagoya Imperial University changed its name to Nagoya University in 1947.

was even newer, just created in 1941. Unfortunately, however, the catastrophic situation in the Pacific War did not allow him to concentrate on the physics research. Takeshi Inoue was called up for conscription immediately after he moved with Sakata to Nagoya Imperial University. During the war period, Sakata's theory group was forced to be evacuated to Shinshu (Fujimi village).

Soon after the end of the Pacific War (1945), Sakata reorganized his research group in Nagoya to be administrated under the democracy principle. This actually made his group highly productive.

The problem they tried to resolve at that time was the UV divergence problem in quantum field theories. As Sakata stated clearly in his 1947 paper,[21)] they classified possible sources of particle physics problems into three categories: (i) the propriety of the model, (ii) the limit of the applicability of quantum field theory, (iii) the validity of the approximation method (perturbation theory). Although main stream people in the Japanese particle theory community regarded the divergence problem associated with (ii) or (iii), Sakata and his Nagoya School attacked the problem from the viewpoint of (i): they tried to dig down a little deeper the problem within the perturbative quantum field theory scheme.

Sakata and Hara advocated their C-meson theory[22)] along this line. They tried to resolve the divergence problem of the electron self-energy by introducing a new particle (called C-meson) in the quantum electrodynamics framework. The idea of C-meson was very simple. The photon loop contribution in the electron self-energy was known to be

$$W_E = \frac{e^2}{\hbar c}\frac{mc^2}{\pi}\left(\frac{3}{2}\lim_{K\to\infty}\log K + \frac{3}{2}\log 2 - \frac{1}{2}\right), \tag{2·1}$$

with m and e being the mass and the charge of the electron, respectively. Here the cutoff, denoted by K, was introduced to regularize the logarithmic divergence. In order to solve the divergence problem, Sakata and Hara introduced a hypothetical scalar particle (called C-meson) which was assumed to have Yukawa coupling f with the electron. They then performed exactly the same calculation as Eq. (2·1) for the C-meson loop and found

$$W_M = -\frac{f^2}{\hbar c}\frac{mc^2}{2\pi}\left(\frac{3}{2}\lim_{K\to\infty}\log K - \frac{3}{2}\log\frac{m_u}{m} + \frac{1}{4} - \frac{1}{2}\log 2\right), \tag{2·2}$$

with m_u being the C-meson mass. It was then postulated the relation

$$e^2 = \frac{1}{2}f^2$$

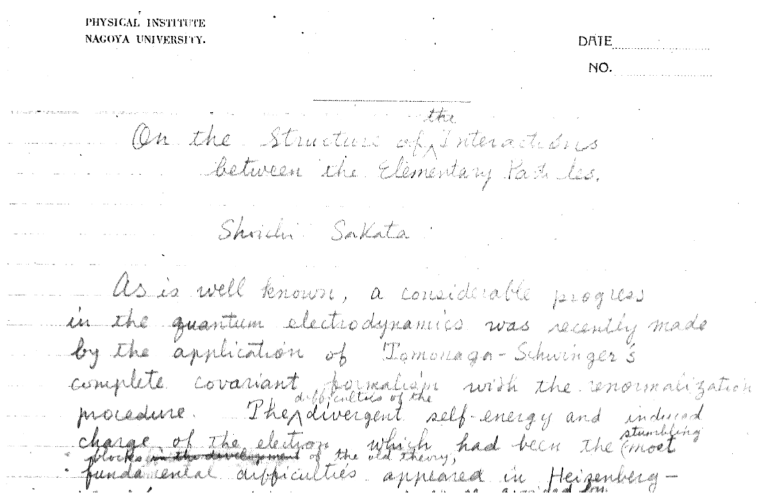
between the coupling strengths, giving the finite value of the total self-energy of the electron,

$$W = W_E + W_M = \frac{e^2}{\hbar c}\frac{mc^2}{\pi}\left(\frac{3}{2}\log\frac{2m_u}{m} + \frac{1}{2}\log 2 - \frac{3}{4}\right).$$

We now know the idea of C-meson theory eventually failed. Thanks to the developments of the renormalization theory, it is now possible to evaluate quantum corrections in QED with extremely high precision, even in the presence of divergences in QED. These divergences can be absorbed in the redefinition of the parameters and can be shown not to affect relationships between physical observables if we renormalize the theory appropriately.

However, the proposal of the C-meson by Sakata and Hara looks appealing to me, even in the light of modern particle theory. This methodology, introducing new degree of freedom to solve some problem, is nothing but the research direction of modern particle model builders. Moreover, the proposal of the C-meson theory influenced the developments of the renormalization prescription done by Tomonaga's group. I learned this from Professor Kinoshita when he gave us a talk[23] at the $pn\Lambda 50$ symposium, a conference celebrating the 50th anniversary of the Sakata model. He explained how C-meson theory helped Tomonaga's group to reorganize the properties of various divergences appearing in QED. We can trace the path how Tomonaga's group eventually reached the renormalization idea, starting from Sakata's C-meson theory, in a series of papers published in the same issue of Progress of Theoretical Physics.[24)–26)]

After the developments of the renormalization theory, Sakata and his Nagoya School continued their researches on the divergences in quantum field theories. They regarded the renormalization theory as an abstract formalism, behind which the concrete structure of the particle should be hidden. Sakata, Umezawa and Kamefuchi wrote a couple of papers in 1951[27] and in 1952[28] in accord with this thought. As Sakata, Umezawa and Kamefuchi stated in Ref. 27), so long as the renormalization procedure is successful, it is unnecessary to know the detailed features of the structure. But, as soon as defects of the renormalization theory become obvious, we must seriously consider the structures of the elementary particles. In this sense, non-renormalizable interactions are much important compared with the renormalizable ones, because they indicate the existence of the underlying structures of the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On the Structure of the Interactions between the Elementary Particles.

Shoichi Sakata

As is well known, a considerable progress in the quantum electrodynamics was recently made by the application of Tomonaga-Schwinger's complete covariant formalism with the renormalization procedure. The difficulties of the divergent self-energy and induced charge of the electron, which had been the most stumbling blocks of the old theory, fundamental difficulties appeared in Heisenberg-

Fig. 2. Unfinished paper draft by Sakata discussing the applicability of the quantum electrodynamics. (SMAL 51 01 WP 01)

elementary particles. In the light of modern particle physics, this philosophy can be regarded as an early attempt to build the effective field theory method. In the effective field theory method, we do not care about the renormalizability of effective interactions. Instead, we seek for the underlying physics behind these nonrenormalizable interactions. In Refs. 27) and 28), Sakata, Umezawa and Kamefuchi tried to classify the general types of the elementary particle local interactions by whether they are renormalizable or not. Their classification method, based on the dimensionality of the interaction, is now well-known and widely explained in modern quantum field theory textbooks.

2.4. *Sakata model*

Sakata stayed at the Niels Bohr Institute (then the Institute for Theoretical Physics), Copenhagen University from May to October 1954 at the invitation of N. Bohr and C. Møller. This was the time of the particle explosion: A lot of new particles were discovered during the 1950s. During his stay in Copenhagen, Sakata gave a talk titled "Some recent research work in Japan", the manuscript of which is now achieved in SMAL (54 01 WP 01). In this talk, Sakata introduced works of young Japanese researchers, especially emphasizing the work done by Nakano and Nishijima[29] on the properties of V-particles.

After Sakata returned to Nagoya, Sakata and his Nagoya School started researches trying to uncover the physics behind the Nakano-Nishijima-Gell-Mann rule.[29] In September 1955, Sakata finally got the idea of his famous Sakata model, in which p, n, and Λ were assumed to be elementary, while the other hadrons were considered as composites made from p, n, Λ and their anti-particles, a generalization of Fermi-Yang model of composite pions.[31] The Sakata model was reported as an extra lecture given at the annual meeting of Physical Society in Japan in October 1955. The paper was then published in 1956.[30] At the occasion of $pn\Lambda$ symposium in 2006, Professor Matumoto told us a story of the birth moment of the Sakata model.[32] From his talk, I learned that Sakata got his idea of the Sakata model

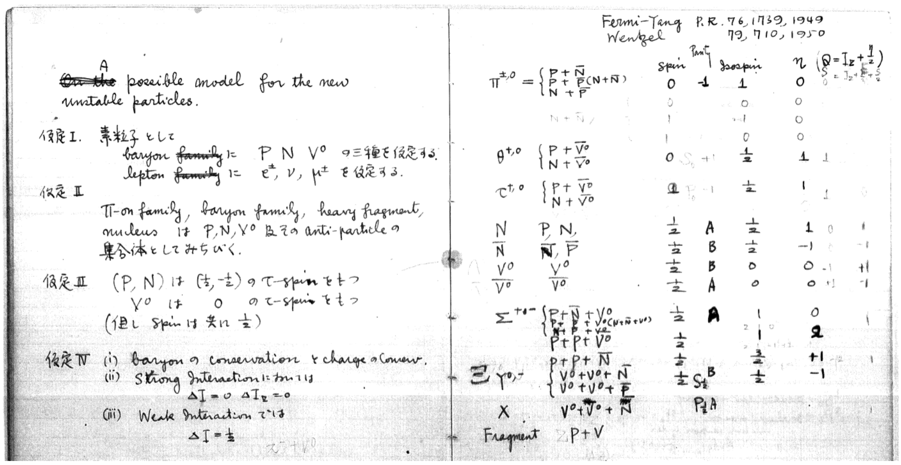


Fig. 3. Sakata's note discussing his composite hadrons model. (SMAL 55 01 NB 02)

after long discussion at his Nagoya School group meeting. At the meeting, Sho Tanaka reported his attempts to understand the kaon as an excited state of π in the Fermi-Yang model. The moment of the birth of Sakata model is also recorded in Sakata's pocket diary (SMAL archive, 55 01 NB 01) and his research notebook (SMAL archive, 55 01 NB 02).

Members of Sakata's Nagoya School actively studied phenomenological and theoretical aspects of the Sakata model. Sho Tanaka proposed a modification of the Sakata model so as to explain the θ-τ puzzle in the composite model framework.[33)] Ziro Maki tried to formulate a covariant theory of bound states for the Sakata model.[34)] Ken-iti Matumoto derived a semi-empirical mass formula[35)] for new particles on the basis of the Sakata model.

A revolutionary progress was then made by Ogawa,[36)] by Yamaguchi[37)] and by Ikeda, Ogawa and Ohnuki.[38)] In Ref. 36), S. Ogawa proposed the exchange symmetry under $p \leftrightarrow \mathit{\Lambda}$ and $n \leftrightarrow \mathit{\Lambda}$ in the Sakata model. Similar symmetry was proposed by Yamaguchi.[37)] Ogawa's symmetry was then extended to $U(3)$ symmetry

$$\begin{pmatrix} p \\ n \\ \mathit{\Lambda} \end{pmatrix} \to U \begin{pmatrix} p \\ n \\ \mathit{\Lambda} \end{pmatrix},$$

by Ikeda, Ogawa and Ohnuki.[38)] Sawada and Yonezawa[40)] then tried to modify the Matumoto mass formula in accord with the $U(3)$ symmetry. We now know that the discovery of $U(3)$ symmetry gave a huge impact on the particle theory. Although the Sakata model was eventually superseded by the quark model, the flavor $SU(3)$ symmetry played the most essential role in the era of the quark model developments. Moreover, the symmetry concept now becomes one of the most important aspects in modern particle physics. Professor Ohnuki gave us a very impressive talk about his recollections on his discovery of the $U(3)$ at the $pn\mathit{\Lambda}$ symposium.[39)]

I was also impressed by the episodes introduced by Professor Sawada at the same symposium.[41)] Faced with the phenomenological success of the eightfold way model (octet baryons), in 1963, a year preceding the quark model, Sakata postulated the existence of so-called ur-baryons (ur-proton, ur-neutron, and ur-$\mathit{\Lambda}$), hypothetical constituents of the octet baryons. When Gell-Mann and Zweig proposed their quark model in 1964, Sakata highly evaluated the quark model as the simplest ur-baryon model least modified from the original Sakata model.

2.5. *Neutrino mixings*

Encouraged by the success of the Sakata model, Sakata and his Nagoya School tried to extend the Sakata model to describe both hadrons and leptons in a unified manner. At that time, the weak interaction universality among baryons and leptons was just discovered in the Feynman-Gell-Mann current-current interaction framework.[42)] It was then pointed out by Gamba, Marshak and Okubo that the weak interaction Hamiltonian possesses an invariance under the simultaneous exchanges of

$$p \leftrightarrow \nu, \quad n \leftrightarrow e^-, \quad \mathit{\Lambda} \leftrightarrow \mu^-,$$

in the Sakata model framework. This fact was called "Kiev symmetry" because it was first pointed out at the Kiev conference. In 1960, Maki, Nakagawa, Ohnuki and Sakata proposed a unified model of hadrons and leptons, called Nagoya Model, in order to explain the physics behind the Kiev symmetry in a composite model framework.[43)] Maki, Nakagawa and Sakata then tried to incorporate the two distinct types of neutrinos (ν_e and ν_μ), as postulated by Sakata and Inoue in their two meson theory, into the composite model framework (New Nagoya Model).[44)]

These attempts were too ambitious at that time. We now know they failed to construct a calculable composite model framework which can be compared with various experiments. However, the deep consideration made by Sakata and his Nagoya School on their model caused a miracle. They reached the correct theory of neutrinos explaining how neutrinos mix each other in the presence of their masses. This is the reason why the neutrino mixing matrix is now named MNS (Maki-Nakagawa-Sakata).

Maki, Nakagawa and Sakata started from the leptonic weak current

$$j_\lambda = (\bar{\mu}_0, \bar{e}_0)\gamma_\lambda(1-\gamma_5)\begin{pmatrix} \nu_{\mu 0} \\ \nu_{e0} \end{pmatrix},$$

and the mass matrices Λ and Λ'

$$(\bar{\mu}_0, \bar{e}_0)\Lambda\begin{pmatrix} \mu_0 \\ e_0 \end{pmatrix} + (\bar{\nu}_{\mu 0}, \bar{\nu}_{e0})\Lambda'\begin{pmatrix} \nu_{\mu 0} \\ \nu_{e0} \end{pmatrix}.$$

They then explicitly diagonalized these mass matrices and obtained (assuming $m_e = m_{\nu 1} = 0$) the mass eigenstates (the true neutrinos) ν_1 and ν_2

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

with ν_e and ν_μ being the weak neutrinos

$$j_\lambda = \bar{\mu}\gamma_\lambda(1-\gamma_5)\nu_\mu + \bar{e}\gamma_\lambda(1-\gamma_5)\nu_e.$$

Maki, Nakagawa and Sakata then pointed out the similarity of their neutrino mixings with the modified baryonic weak current suggested by Gell-Mann and Lévy[45)] at that time,

$$J_\lambda = \bar{n}\gamma_\lambda(1-\gamma_5)p\frac{1}{\sqrt{1+\epsilon^2}} + \bar{\Lambda}\gamma_\lambda(1-\gamma_5)p\frac{\epsilon}{\sqrt{1+\epsilon^2}}.$$

When I read the Maki-Nakagawa-Sakata paper, I was impressed very much by the fact that MNS reached the correct theory of the neutrino mixings starting from the correct assumption (the weak coupling universality) but through the path eventually turned out to be failed (the New Nagoya Model).

I have a couple of remarks on the Maki-Nakagawa-Sakata paper. The first point is its date received by Progress of Theoretical Physics, June 25, 1962. The existence of two kinds of neutrinos was experimentally confirmed by the famous Brookhaven AGS experiment[46)] reported in Physical Review Letter in the same year. Were

Sakata and his Nagoya School members aware of the result of this experiment? The Brookhaven neutrino experiment paper[46)] was received by PRL on June 15, 1962, only 10 days prior to the Maki-Nakagawa-Sakata paper. It is most likely that Maki, Nakagawa and Sakata did not know the final result of the experimental analysis when they wrote their manuscript. Maki, Nakagawa and Sakata argued that such a high energy neutrino experiment would provide an upper limit on the mass of the second neutrino (ν_2). Of course, they were informed that the Brookhaven neutrino experiment was ongoing at that time. Moreover, C. Iso, who stayed in US at that time, sent a couple of letters to Japan, mentioning a rumor about the preliminary result of the Brookhaven experiment he heard in the Boston area. I heard that the MNS paper was directly influenced by these letters of Iso reporting the experimental verification of the two kinds of neutrinos. My second remark is related with the lepton flavor numbers. As studied by several theorists in 1957–1960 and emphasized by Lee and Yang[47)] in 1960, the existence of two kinds of neutrinos was theoretically motivated by the absence of the $\mu \to e\gamma$ decay mode. The New Nagoya Model violates the conservation of the lepton flavor number, however. We should thus, in principle, worry about the lepton flavor violation (LFV) decay mode $\mu \to e\gamma$ in the New Nagoya Model. Had the Nagoya School estimated the branching fraction of this decay mode? Yes, they had certainly estimated it. Their result on the LFV decay was published in their subsequent paper.[48)]

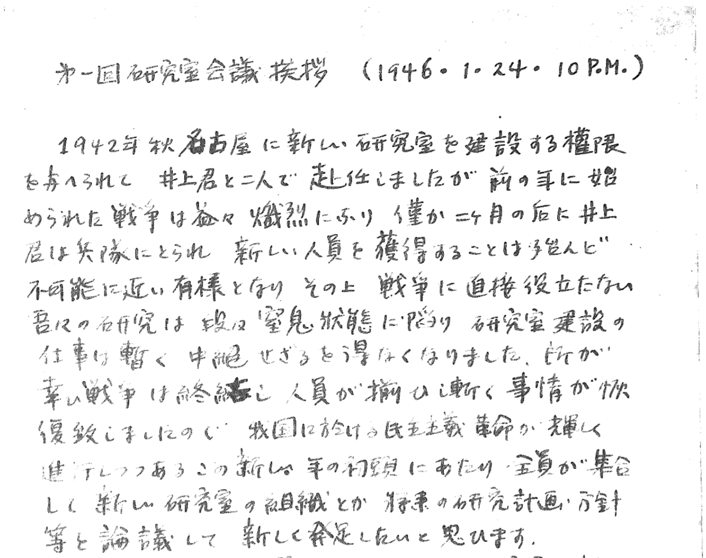
§3. Sakata's leadership in his Nagoya School

Immediately after the end of the Pacific War, Sakata reorganized his particle theory research group in Nagoya to be administrated under the democracy principle. As the first step, he proposed to establish monthly group meetings called "Laboratory Council" in his group. The purpose of the "Laboratory Council" was to decide the research direction of the group in a democratic manner, as well as to discuss related subjects including the personnel arrangements, the budget, and the educational matters of the group. This is in contrast to the the feudalistic administration policy under which only a privileged leader (professor) in each research group can decide these things. Sakata's proposal, relinquishing these powers to the "Laboratory Council", should therefore be regarded as a shocking and radical proposal at that time.

What was the aim of this democratization? Sakata explained his idea in his address given at the inaugural meeting of "Laboratory Council" held on January 24, 1946. The manuscript of his address is archived in SMAL as 46 01 NB 01. In this address, after a brief description of the status of the recovery from the war period damages in his group, Sakata explained the purpose of the meeting, "At the beginning of the glorious democratic revolution year in Japan, I would like to declare the rebirth of our Laboratory, in the meeting all members of us present, discussing the (new) organization of our laboratory and the future plan of our research." Sakata then emphasized the importance of the efficiency in the organization. "As for the organization matter, in a modern research laboratory, it goes without saying that everything should be arranged so as to maximize its research productivity. For such a purpose, we must establish a rational organization without having irrational elements (traditions)." Sakata did not jump into technical issues to establish such an ideal organization. Instead, he raised a couple of fundamentally important principles for the administration in his research group. "There are two important principles for the organization in our laboratory: 1) perfect freedom in the research of each member in our laboratory. 2) the total outputs of our laboratory should be more than the simple sum of activities of individual members." Sakata raised his first principle because any research progress ultimately owes to activities of each individual researchers. On the other hand, he pointed out the importance of his second principle because the increasing complexities of the modern science make it rather ineffective or almost impossible to perform scientific research by a single person. The problem is therefore how to keep a harmony between these two seemingly frustrating principles. For Sakata, "Laboratory Democracy" was the best tool to achieve this harmony: each member enjoys his research, collaborating with other members of the group, after having thorough and democratic discussions on the research direction at the "Laboratory Council".

Sakata succeeded in organizing his research group (Sakata's Nagoya School, or E-ken) under the Laboratory Democracy. This made Sakata's group highly productive as he intended. Moreover, the "Laboratory Democracy" had shown itself as a very effective framework to train a young researcher to acquire research skills to become an independent researcher. This was one of the reasons why so many glorious physicists were brought up as Sakata's disciples in his Nagoya School.

Sakata then extended his idea of "Laboratory Democracy" to the entire Physics Department. The new democracy system of Physics Department was described in the "Charter of Physics Department", which was established on June 13, 1946. The



第一回研究室会議挨拶 (1946・1・24・10 P.M.)

1942年秋名古屋に新しい研究室を建設する権限
を与へられて 井上君と二人で赴任しましたが 前の年に始
められた戦争は益々熾烈になり 僅か二ヶ月の后に井上
君は兵隊にとられ 新しい人員を獲得することは殆んど
不可能に近い有様となり その上 戦争に直接役立たない
吾々の研究は殆ど窒息状態に陥り 研究室建設の
仕事は暫く中絶せざるを得なくなりました。所が
幸い戦争は終結し 人員が揃ひ漸く事情が恢
復致しましたので 我国に於ける民主主義革命が輝しく
進行しつつあるこの新しい年の初頭にあたり 全員が集合
して 新しい研究室の組織とか 将来の研究計画、方針
等を論議して 新しく発足したいと思ひます.

Fig. 4. Sakata's address given at the inaugural meeting of "Laboratory Council". (SMAL 46 01 NB 01)

perfect democracy among research members of Physics Department, including both faculty members and students, was clearly stated in the Charter. We still keep the idea of the Charter for our administration of Physics Department and celebrate "the Charter Day" every year on June 13.

§4. Summary

Theoretical particle physics is now faced with various unsolved questions and difficulties. Among them, the issues related with the TeV scale physics are now actively explored at the LHC, which we hope to cause a revolution in the particle physics in the near future. In this sense, we are living in the predawn of the coming particle revolution just like Sakata and his Nagoya School. Although the situation surrounding us today is quite different from that of Sakata's age, I hope, Sakata's way of thinking still gives us some hints for our own researches.

Before closing my presentation, I would like to show you a calligraphy drawn by Sakata in 1969, one year before his death. The words "To hear all and any makes you enlightened, to hear one and only makes you benighted" were taken from "Tsu Chin T'ung Chien" (ancient Chinese history book compiled in 1084). This shows concise thoughts of Sakata who pointed us the right direction in those chaotic days of physics where many competing approaches coexisted.

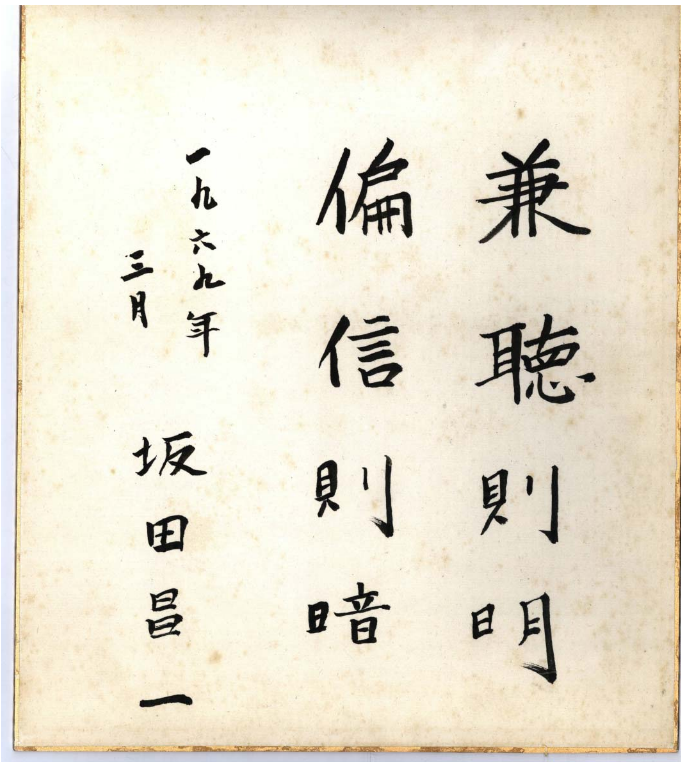


Fig. 5. Sakata's calligraphy drawn in 1969.

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