The Sakata Model and Its Succeeding Development
toward the Age of New Flavours

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It is my great honor to make a talk on the above title at the Jubilee of the advocation of meson theory by the late Professor Yukawa. It is especially so because the late Professor Sakata, who was my teacher, was the first collaborator of meson theory and also the first pupil of Professor Yukawa.

I

Now, first I would like to begin with a comment on the title "the Sakata model", the physics content of which is well-known. Complying with the strangeness quantum number by Nakano, Nishijima and Gell-Mann, the $\Lambda$-particle as a carrier of strangeness, was introduced to be the third fundamental entity in addition to the proton and the neutron in Fermi and Yang's composite model. Sakata was much interested in the methodological approach based on his philosophy—the dialectic materialism which he had been baptized in his high school days. He also frequently referred to Taketani's three stage theory of epistemology which asserts that our recognition proceeds through three stages: the phenomenological, substantialistic and essentialistic ones. Sakata seemed to regard the substantialistic stage as an important step and had, in fact, a very keen sense in the introduction of new entities as well as in the model building.

As to the Sakata model itself, he stated in March, 1963 about one year earlier than the proposal of the ace-quark, "In the background of the composite model which I advocated, there lies an idea which expects the existence of an inexhaustible level structure of matter ... If G and N's (Gell-Mann and Ne'eman's Eightfoldway) theory is found experimentally to be better than the I. O. O. (Ikeda-Ogawa-Ohnuki's) theory, we must accept first the eight baryons to belong to the same level, and proceed to assume the existence of $ur$-proton, $ur$-neutron and $ur$-$\Lambda$-hyperon behind them —this is what I proposed. The viewpoint that there must underlie inevitably a "logic of matter" beneath the symmetry, is characteristic to the methodology implied by my proposal of the composite model". Namely the Sakata model was an expression of his methodology as well as an advocation of a physics idea for him.

I should like to add another plea in my report. Contrary to the prejudice about his personality which some one might have, Sakata was of mild character and open-hearted. He had a deep influence on the younger generation by his physics and also by his philosophical idea, and formed, I dare to say, a certain school of researchers around him, whose boundary was, of course, unfixed and changed in time. What I want to introduce
here, are the works performed by the school subsequent to the Sakata model. So I should apologize, in advance, that my report will be limited to those of my personal contact and that I might make serious omissions.

II

Now, I think, a fresh turn for the meson theory after the Sakata model was brought first by Matumoto's advocation of mass formula for hadrons, which showed that $\pi$-nucleon resonances and K-Y system should be treated on the same footing. It was contrasted with the general attitude at that time which aimed to derive the (3·3) resonance in terms of Yukawa interaction between $\pi$-meson and the nucleon. The Sakata model also offered another material base $\Lambda$ which promoted the unified understanding of the weak interaction in terms of the weak Fermi interaction. It is worth recalling further that Sakata also had introduced $\mu$-on and its associated neutrino early during World War II with Inoue. Meanwhile, Oneda informed us that the Sakata model predicts the absence of semi-leptonic decay $\Sigma^+ \rightarrow n + e^+ + \nu$ in contrast with the allowed $\Sigma^- \rightarrow n + e^- + \bar{\nu}$ decay.

According to the characteristic feature of the model itself, the Sakata model subsequently activated the introduction of the unitary symmetry $U(3)$ as the extension of $SU(2)$ of the proton-neutron system combined with the baryon number conservation. The symmetry, as was advocated by Ikeda, Ohnuki and myself, and independently by Yamaguchi, initiated the next stage of development. Its irreducible representations specified what combinations of iso-spin and strangeness forms a particle multiplet, and provided the problems for experimental verification of the model together with the mass formula by Sawada and Yonezawa. Especially the $(0^-)$ meson octet was first recognized to exist with correct energy levels. The symmetry was also applied to the weak decay processes, which, however, I shall omit here. Around that time Fujii introduced the neutral vector field in $U(3)$ invariant way for the Sakata model, but regrettably missed a further development.

Now, I have frequently been asked the question "Why didn't you notice the baryon octet?". Each colleague of mine will have each his own answer. In my case the story is as follows: when I was preparing the first draft of the symmetry of Sakata's model in the summer of 1958, the existence of eight baryons was widely known together with the "global symmetry", while the information about the spin for each baryon was not all settled experimentally. I was in some temper to cope with the global symmetry especially because my first letter submitted to the Progress of Theoretical Physics has once been returned with a referee's comment that the proposed one was little different from the global symmetry. The progress at the beginning has urged me to stick to the Sakata model until the spin of $E$ was settled. In our scheme $E$ belonged to the same multiplet as the $(3·3)$ resonance and was expected to have spin $3/2$. Meanwhile my concern was gradually transferred to the dynamical problem which I shall refer to in the next section.

But before entering there, I must introduce the countermove in Nagoya with the octet baryon after Sakata's statement in March, 1963. It is better to refer to Sakata's talk at the meeting in February, 1964. "Yesterday Nakamura gave a talk on "a complete, short story". My talk is concerned with our long novel since 1956. Yukawa also writes a long

*) Yamaguchi noticed the possibility of the octet baryon in the communication to Nagoya group.
novel, which is predetermined to conclusion. On the contrary, our long novel is never-ending. The plot of our long novel is that the elementary particle is regarded merely as one of inexhaustible strata that the structure of matter implies, and a variety of characteristic properties of particles at present—"Form"—are to be grasped by "logic of matter" in the next deeper strata... At a meeting on the model of elementary particles which was held at Hiroshima during March, 1964 [sic], I made three proposals. The first proposal was the following: In the instance where the octet scheme of the baryon is consistent with experiment, the scheme must be incorporated in our novel; on that account it may be reasonable to make the fundamental particles $p$, $n$ and $\Lambda$ of the composite model no more correspond to real particles but to consider the fundamental particles as "Urteilchen", while the real proton, neutron and $\Lambda$-particle should be treated on the equal footing to the $\Sigma$- and $\Xi$-particles. Along this way, Maki and Ohnuki\textsuperscript{18} recently wrote a chapter of our river novel. Hara and Gell-Mann\textsuperscript{19} also made similar works in a little different spirit". In fact, Maki and Ohnuki proposed the quartet scheme of the fundamental particles as "$\chi_0$", "$\psi$", "$n$" and "$\Lambda$", where " " is attached to indicate the discrimination from the real particles. In this scheme, the octet baryon was formed by "$\chi_0$" combined with the octet meson, and the octet meson was composed of triplet "$\psi$", "$n$" and "$\Lambda$" and its anti-triplet. Sakata also presented, in the same talk, discussions about some alternatives for choosing the fundamental particles but holding the integral charge, and about the baryon-lepton symmetry in terms of the possible new fundamental particles. The above is the correspondence in Nagoya at that time.

Now, going back to early fifties we recall that the meson dynamics had been in a mess owing to the failure of its perturbation treatment applied to the meson-nucleon scattering which was so successful in QED. The situation was never exceptional for the research of nuclear force. In this rather discouraging situation, Taketani, Nakamura and Sasaki\textsuperscript{21} expected, by taking account of the correspondence principle that the nuclear force in the outer region (say $\approx 1.5 \mu^{-1}$; $\mu^{-1}$ is the $\pi$-on Compton wave length) could be yet described perturbation theoretically by Yukawa's meson theory. The proposal had been successfully examined by Iwadare, Otsuki, Tamagaki and Watari\textsuperscript{22} in the analysis of the deuteron problem as well as of the low energy nucleon-nucleon scattering ($\approx 20$ MeV). But toward the end of 50's the experimental informations about nuclear force in some hundreds MeV has been accumulated, and the conflict between the theoretical expectation including even the higher order mesonic effects\textsuperscript{23} and the experiment had clearly been disclosed about the inner region of nuclear force.

In touch with the situation after some achievements of the Sakata model, we gradually formed the following idea, "In the composite theory, the strong interaction should be derived from the fundamental interaction between the fundamental particles, and the Yukawa interaction observed between pion and nucleon is regarded as a "model" Hamiltonian... Higher order effect should not be taken for the Yukawa interaction as they stand in the usual field theory because such effects should be considered in the fundamental interaction, not for the model Hamiltonian. The Yukawa interaction, as a model Hamiltonian, will already contain some of the higher order effects of the fundamental interaction in a certain correlated form. In such a situation, the higher order effects
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Fig. 1. Rearrangement of sakatons.

Fig. 2. Taken from S. Sawada et al., Prog. Theor. Phys. 28 (1962), 991.

Fig. 3. Taken from M. Imachi, et al., Prog. Theor. Phys. 38 (1967), 1198.

of the model Hamiltonian may have less importance\(^\text{24}\). Hoshizaki, Otsuki, Watari and Yonezawa\(^\text{25}\) first applied in 1961 the idea yet in some vague stage to the study of nuclear force, which was shown as to take the Feynman diagram of just the lowest order depicted in Fig. 1. But the contribution should be taken over all the composite bosons expected in the Sakata model. The method was more elaborated by Sawada, Ueda, Watari and Yonezawa\(^\text{26}\) in 1962, and extended to the meson-nucleon scattering as is shown in Fig. 2 and also to the inelastic cases. The summation should be taken over all composite mesons and fermions, respectively. They called the method OBEC (one-boson (baryon)-exchange-contribution), but it was later known as the “interference model”. After the advocation of the rule by Okubo, Zweig\(^\text{27}\) and especially by Iizuka\(^\text{28}\) who has explicitly relied on the existence of constituent, the successive development led Imachi, Matsuoka, Ninomiya and Sawada\(^\text{29}\) to the initiation of the quark line approach in 1967, as is also shown in Fig. 3, which came to the “duality diagram method” through finding of the duality in the amplitude analysis\(^\text{30}\) of hadron reactions by Igi and Matsuda, etc.

IV

In the last, going back again to the past, I should like to introduce the advocation of new flavours in Japan. The beginning of this problem can be traced back to the end of 1950’s, when the study of unitary symmetry for the Sakata model just started. As I recall, in the meeting held in November of 1959 at the Institute of Fundamental Physics, Maki, Nakagawa, Ohnuki and Sakata\(^\text{31}\) proposed the so-called Nagoya model in which the proton, neutron and \(\Lambda\)-particle are assumed to be composite systems of \(B\)-matter combined with neutrino, electron and \(\mu\)-meson, respectively. The idea was stemmed from the baryon-lepton symmetry\(^\text{32}\) by Marshak and others. According to Sakata’s philosophy, the symmetry should be understood as inherent in the structure of those fundamental particles \(p, n\) and \(\Lambda\) itself. That is to say the weak interaction was ascribed to that of
leptons, while the unitary symmetry among $p$, $n$ and $A$ is due to the common matter $B$ as the source of strong interaction.

In a study meeting in 1962, however, we were informed that BNL experiment found two types of neutrino discriminating the electron neutrino from the $\mu$-meson's one. I came back to Hiroshima with a thought that the baryon-lepton symmetry had been crashed. So it was surprising for me that two papers were found in Progress of Theoretical Physics, which, still sticking to the baryon-lepton symmetry, proposed the possible existence of the fourth fundamental entity $p'$, independently written by Kyoto group-Katayama, Matumoto, Tanaka and Yamada who were in Kyoto at that time and also by Nagoya group-Maki, Nakagawa and Sakata. I think, these proposals in 1962 which we call as the New Nagoya model were the first advocations on charm freedom, although as the extension of Sakata model and not of the ace-quark model. By the way I should like to note two things about these papers. The first is that the Cabibbo universality of weak interaction has already been recognized as the natural consequence of the model prior to the proposal of Cabibbo himself in 1963. The second is the possible neutrino oscillation between flavors which was first noticed by Nagoya group, and now still attracts the keen interest for the experimental verification.

Time has passed and just before the summer vacation in 1971, I had unexpectedly the telephone call from Niu at the Institute of Nuclear Research about the curious event observed in the emulsion exposed to the cosmic-ray.

The cosmic-ray experiment, once being the forerunner of high energy physics, has gradually fallen behind the accelerator physics after 1950. The cosmic-ray physicists scattered into the fields of accelerator- and of astro-physics. The general trend was similar also in Japan, but was not so drastic as in the western world, probably because the high-energy machine experiment was unhappily belated in Japan. Niu, Mikumo and Maeda aimed to clarify the detailed mechanism of multiple production and made a special devise to precisely identify the charged tracks in emulsion exposed to the cosmic ray. The famous event they found is schematically shown in Fig. 4. The point is the charged track $X$ which emerges from $O$ and deflects at $B$, being accompanied by the $\pi^0$-emmission in the opposite side.

The event could be interpreted as the secondary collision of the charged particle emitted from the first vertex $O$. But at the point $B$, there was found no black and grey tracks which was characteristic indication of the collision with the emulsion nucleus, and the momentum balance in the $x$-$y$ plane vertical to the track $\overrightarrow{OB}$ seemed to be quite satisfactory. So it was not plausible to ascribe the event to the collision of the secondary charged particle. Niu and his collaborators interpreted the event as that a certain particle $X$ was produced at $O$ and decayed at the point $B$ such that

$$X \rightarrow X^{ch} + \pi^0$$

and estimated the life-time of $X$ as follows:

<table>
<thead>
<tr>
<th>Assumed decay mode</th>
<th>Mass of $X$ in GeV</th>
<th>Life time in Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X \rightarrow \pi^0 + \pi^\pm$</td>
<td>1.78</td>
<td>$2.2 \times 10^{-14}$</td>
</tr>
<tr>
<td>$X \rightarrow \pi^0 + \rho$</td>
<td>2.95</td>
<td>$3.6 \times 10^{-14}$</td>
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</tbody>
</table>
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Figure 1. Plate Number

Figure 3(a). Y Projection

Figure 3(b). X Projection

Figure 3(c). Z projection

Fig. 4. Taken from K. Niu et al., Prog. Theor. Phys. 46 (1971), 1644.
Table I. List of papers relating to the charmed particle which have been published in Progress of Theoretical Physics before the finding of $J/\psi$ after Niu’s discovery.

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Volume (Year), Page</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>“A Possible Decay in Flight of a New Type Particle”</td>
<td>46 (1971), 1644.</td>
<td>K. Niu, E. Mikumo &amp; Y. Maeda</td>
</tr>
<tr>
<td>2.</td>
<td>“Fundamental Quartets and Chiral $U(4) \times U(4)$”</td>
<td>46 (1971), 1647.</td>
<td>Z. Maki &amp; T. Maskawa</td>
</tr>
<tr>
<td>5.</td>
<td>“Quartet Models Based on Fundamental Particles with Fractional Charge”</td>
<td>47 (1972), 982.</td>
<td>M. Kobayashi, M. Nakagawa &amp; H. Nitto</td>
</tr>
<tr>
<td>7.</td>
<td>“Quartet Scheme of Hadrons in Chiral $U(4) \times U(4)$”</td>
<td>47 (1972), 1662.</td>
<td>Z. Maki, T. Maskawa &amp; I. Umemura</td>
</tr>
<tr>
<td>15.</td>
<td>“Further Comments on Quartet Models on Fundamental Particles with Fractional Charge”</td>
<td>49 (1973), 1322.</td>
<td>M. Nakagawa &amp; H. Nitto</td>
</tr>
</tbody>
</table>

With some other detailed information, Hayashi-Kawai-Matsuda-Shige-eda and myself in Hiroshima have analyzed the event and concluded that the event was kinematically impossible to be ascribed to the decay of a usual strange particle, and further anticipated that $X$-particle might be a new particle including the fourth constituent $p'$ in the New Nagoya model. It was because the life-time was consistent with that estimated by the usual weak interaction and the photograph showed another kink track $OCC'$ which could be regarded as the indication of pair production of the new particle like once the case for the strange particle.

The information of $X$-particle as a possible candidate of charm particle —of course the name came later— has immediately attracted the attention of theoretical physicists in Japan, and many related papers have successively appeared in the Progress of Theoretical Physics, as are shown in Table I. You will find there the names of Sakata school. Tomorrow Kobayashi might introduce the situation in Sakata’s laboratory at that time when he joined the study of New Nagoya model and when, sadly, ten months had passed after the death of Sakata. Among the papers in Table I, you will also find in No. 13 the
famous paper written by Kobayashi and Maskawa\cite{36} in 1973, which advocated the three generations for the constituents of hadron to accommodate with CP violation. In the next year 1974, we were excited at the news of $J/\psi$\cite{37} which Ting will introduce to us.

Now I should like to close my talk. Thank you.

References and addenda

3) The concluding remarks of a talk by Sakata given at a research meeting held at Hiroshima Univ., and originally published in Japanese; Soryushiron Kenkyu (Kyoto) 28 (1963), 110. Translated in English, Ref. 1), 208.

In this connection I should like to bring to your notice the following: The octet baryon has been realized by giving up the original Sakata model, but the substantialistic viewpoint, and accordingly $U(3)$ was recovered again by the introduction of the ace-quark. The recognition that the baryon is composed of three quarks (qqq) in contrast with the meson (qq) in spite of both the same octet in $SU(3)$, was essential for the further development of hadron physics. So the Sakata model was not wrong in its methodology, although we must, of course, appreciate the achievement of the ace-quark which extended the concept of matter (as a fundamental entity) by removing the yoke of unit charge.

5) K. Matsumoto, Prog. Theor. Phys. 16 (1956), 686. I should like to refer to the following two papers in the same issue which were performed under Sakata.


The former work was originally initiated at the early time of 1955, on the basis of the Fermi-Yang model. The group discussion held at the end of September in 1955 about Tanaka's work urged Sakata to think of his model. The latter work gives the first treatment of Sakata's composite model in the framework of field theory.

13) Y. Fujii, Prog. Theor. Phys. 21 (1959), 232, was written in Sakata’s laboratory.

For a more elaborate version, see
   See also Ref. 10.
36) See Table I.