On Present-day Problems in Theory of Elementary Particles*)

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*) This paper was read at the research symposium on fireballs and particles in ultra-high energy nuclear interactions, March 23 ~ 25, 1980, Research Institute for Fundamental Physics, and is adjusted in detail and translated into English by Prof. M. Nagasaki.

§1. On New Physics

Through the Japan-Brasil Collaboration in cosmic-ray experiment, there have been discovered the events of production and decay of H-quantum, SH-quantum and UH-quantum in the phenomena of multiple production of mesons. They found other interesting events, too, such as the Centauro type, in the same region of extremenly high energy. Experimental reports were published so far about these findings,[1] and their theoretical implications were synthetically discussed in a special issue of Supplement of Prog. Theor. Phys. in 1973.[2] Later on, the experimental accuracy has been improved, and still more events have been discovered.[3] This issue also contains their report of recent experimental results.

I discussed the meaning of the importance of these findings in Prog. Theor. Phys. Suppl. No. 54 (1973), and also in my pamphlet "Opening door to new physics" distributed together with it.

Almost all research workers of the theory of elementary particles seem to consider that the gauge theory or "the unified theory of all fundamental forces" has been a recent success in the theory of elementary particles. "New physics" that I mean, however, does not indicate the sort of things such as quark, charm, colour, gluon, weak boson, and so on, because all these things are what were considered on inferences from the theories hitherto presented, ranging from Sakata's two meson theory up to the Sakata model, Nagoya model and others, and are what have been assumed in order to reinforce these former theories.

"New physics" is the one that is concerned with such things as H-, SH- and UH-quanta, Centauro phenomena and the related events, which were not expected at all from the former theories. These phenomena at ultra high energies are entirely new, and are named "new states of matter" by C. M. Lattes. They are not theoretically explained yet, and are not what could be deduced from the former theories. Jet events which correspond to H-quantum events are observed also in accelerator experiments,*) much later than the proposition of H-quantum hypothesis in 1961 through the analysis of jet phenomena in cosmic ray experiments. Though particle physicists usually deal with them on the assumption of hadromization of quarks or gluon, this assumption is not so clear as the H-quantum hypothesis about the mass of the jet event.

The existences such as SH- and UH-quanta with the specified values of mass of about 20 and 200 GeV, respectively, as well as the entirely new events related to them, can not be explained and not also be expected by the former theories. It is therefore necessary to advance the theory, on the supposition of the existence of the entirely new states of matter with their characteristic values

*) The reader is referred to the other papers in this issue for the analyses of the jet events observed in accelerator experiments with the fire ball model.

of mass, rather than consider these jet events in the framework of the theories hitherto presented.

I do not say that it is meaningless at all to conceive the unified theory in the present framework. But, it is difficult to think that a unified theory will be completed without notice of these clear and new events.

We should remember that Eddington developed an extensive theory of "proton and electron" around 1930 on the basis of the available knowledge at that time only.

It is necessary for us to see that in physics many current theories prevailed at various times. After the World War II, there have been also a variety of theories such as global symmetry or bootstrap, for example, which were prevalent at some time and went out then. It is of course a natural thing to have a variety of trials. The trouble is that, when a kind of theory goes current, other kinds of theories are neglected almost at all.

At present, theories based on the quark model are prevailing over the world. There is a tendency of neglecting considerations of different kinds, in uncritical relience on the quark model. Although many calculations are done appearently in the style of theory, they turn out on close examination to be partial in their own respects, and not always to be consistent theoretically. Many assumptions introduced unconcernedly into them are passed over. Theories based on viewpoints different from that of the prevailing theory, on the other hand, are treated with neglect after being pointed out imperfections and assumptions, if any, in them. Or, they are criticized of not being full of detailed calculations as in the prevailing theory. Detailed calculations in the prevailing theory are, however, based also on their particular assumptions. Forgetting this fact, people often take them to be successfull because of their ability of explaining some parts of phenomena.

As for the unified theory, the unification in mathematical form does not suffice, though it is interesting, because it is apt to neglect assumptions and premises included in it. One should be careful enough not to forget the unification in physical model itself, or the unification in the substantialistic character of physical theory. It is the viewpoint on the unification in physical model itself that provides us with the real content of the conception of premise and assumption.

We remember the theory of the motion of planets which lasted from the Greek age before Kepler. On the uncritical premise of the principle of circular motion of celestial bodies, they explained and predicted the motion of planets with many epicycles and eccentrics, getting very satisfactory results for the time being. More such circles were added every time when the planets came off their predicted positions as the time passed, so that King Alphonso in 13th century sighed over the complexity of the system of the circles when he made the Alphonso Table. The model of the planetary system became simple and clear at once, however, when Kepler abandoned, on the basis of the heliocentlic theory of Copernicus, the principle of the circular motion of celestial bodies. The way before Kepler in which people incleased the degree of freedom one after another in order to fit their theory to observations, without changing the principle of the circular motion of celestial bodies that constituted their beautiful mathematical unified theory of the cosmos, gives us, I think, a good lesson for the problem we have at present.

§2. Models of elementary particles

(i) The quark model[4] which is prevailing nowadays is a variation of the Sakata model,[5] and is characterized with the fractional charges of its fundamental particles. Although no particle with the fractional charge is discovered yet, the name of quark is used instead of the fundamental particle, or the urbaryon in Sakata's usage, even when their charges are not fractional. According to my thought, elementary particle physics is not, at present, provided with sufficient enough substantialistic arrangement of things, so that it is in the stage of searching for various possibilities.

Problems in present-day theory of elementary particle can be divided broadly into two categories. One is the problem concerned with the structure of elementary particles, and the other is that related to the new state of matter which is represented by the aforementioned fireballs H. SH, UH and Centauro etc. discovered in cosmic ray jet phenomena.

As to the problem of the first category, it is necessary to consider the models ranging from the Sakata model to the neutrino unified theory[6] (São Paulo model[7]).

The way of thinking in the Sakata model traces back to the discussions[8] we had about my study on "the conflict between matter and field" made in the time of World War II.[9] It traces back further to his method of mixed fields.[10] This point will be discussed more in details from the view-point of the field theory in §4. Let us discuss this here from the view-point of the model of elementary particles. Sakata got a hint of this method of mixed fields from Møller and Rosenfeld's work[11] of mixing two types of meson field to overcome difficulties in meson theory. He advanced the method of mixed fields to arrive at the two meson theory.[12]

From the unified theory of boson fields, fermion matter can not be deduced. On the contrary, bosons can be constituted from combinations of fermions. This was firstly done in De Broglie's theory of photon,[13] in which two neutrinos were combined to develop a theory of photon. Fermi and Yang[14] considered then that pions are composed of a pair of nucleon and anti-nucleon.

In the Sakata model proposed in 1955, Sakata considered that pions and K-mesons are composed of combinations of a baryon and an anti-baryon. The characteristics and effectiveness of the

Sakata model lie in the introduction of combinations of a baryon and an anti-baryon to compose pions and K-mesons, by which it became possible to treat elementary particles group theoretically.

Noting the fundamental characters belonging to P, N and Λ, Sakata introduced urproton p, urneutron n and urlamda-particle λ as the fundamental particles possessed of such characters. About that time some composite models were proposed in which pions and K-mesons were taken to be fundamental. But these models were lacking in such symmetry that lead to the development of group theoretical study of hadrons. On account of the symmetry among p, n and λ introduced in the Sakata model, it became possible for the first time to see the parallelism of the family of leptons ν, e and μ to that of the fundamental baryons, that is the B-L symmetry[15] discussed in Kiev conference.[16]

Sakata and his coworkers proposed then the Nagoya model,[17] on grasping substantialistically the B-L symmetry, in which it is assumed that the B^+-matter combines with ν, e and μ to compose p, n and λ, respectively. Further on, Taketani and Katayama proposed the São Paulo model.[7] In this model it is assumed, on the basis of the neutrino unified theory, that e and μ are generated from ν through the loading of the ε-charge from which the electromagnetic charge originates. It is also assumed, corresponding to the B^+-matter in the Nagoya model, that there is the B^+-charge from which the strong interaction originates. Thus, p, n and λ are assumed to be generated through the loading of the B^+-charge onto ν, e and

μ, respectively, of which e and μ are the products of the ε-charge loading onto neutrino.

From the Nagoya model and São Paulo model, the following law was deduced;

Law: The existence of leptons indicates the existence of corresponding baryons, and the existence of charged leptons leads to the existence of corresponding neutrinos.

(ii) About that time, it was observed experimentally that there are two kind of neutrino ν_e and ν_μ, as was predicted in the two-meson and two-neutrino theory proposed in 1943 by Sakata et al..*) The neutrino unified theory itself does not restrict neutrino to be of one kind only. It begins with the unified state of neutrinos of various kinds. Just after the experimental confirmation of the two neutrino theory, Nagoya group[18)] and Kyoto group[19)] introduced, from the decay $K^0 \to \pi^+ + e^- + \bar{\nu}$, a mixing angle of the transformation of ν_e and ν_μ into ν_1 and ν_2. From the B-L symmetry, ν_1 was assigned to correspond to p, and the hadronic part of the weak current was thereby formulated with this mixing angle. The hadronic part of the weak current with a mixing angle of the same kind was introduced afterward by Cabibbo.[20)] With this superposition of ν_1 and ν_2 into ν_e and ν_μ, then, ν_e transmutates into ν_μ and

*) Katayama named ν_e and ν_μ as Paulino and Sakatrino, respectively; cf. Ref. 21).

vice versa through their β-interaction with baryons, as was pointed out in the above paper by Nagoya group. From this, it can be said that the transmutation among neutrinos takes place through the action of the B-matter.

Because of the existence of the neutrinos of two kinds, Maki[21)] and others predicted, quite naturally from the Nagoya model, a new particle $\langle\nu_2 B^+\rangle \to p'$ besides $\langle\nu_1 B^+\rangle \to p$. This model is known as the new Nagoya model.[22)] This new particle was later discovered experimentally by Niu et al.[23)], and was named as X-particle. It corresponds to the freedom which is called as charm nowadays. This freedom is therefore the one that was inferred from the Sakata model and Nagoya model.

On the basis of the neutrino unified theory, in 1965 Katayama and the present author[24)] developed a theory in which the baryon octet and decaplet were deduced with a satisfactory result from the supposition that baryons are generated through the loading of B^{++} onto three leptons ℓ_1, ℓ_2 and ℓ_3: $\langle\ell_1, \ell_2, \ell_3; B^{++}\rangle$. In the case of a charged lepton, ℓ_i here is meant to indicate the state $\langle\nu_i\varepsilon\rangle$ in the sense of the neutrino unified theory. In this case, neutrinos are considered to be in new states different from the ordinary ones. In both the Nagoya model and the neutrino unified theory, the problem of the mechanism of the attaching or loading of B-matter, charge and ε-charge onto leptons and neutrinos was distinctly separated to be clarified in future theory, so that it became possible to put the present situation of particle physics in order.*)

About the model of the attaching of B^{++}, we considered in 1960's the one which is intuitively something like a bag, as is shown in Fig. 1a. Another one which we considered in a discussion with Rikkyo University group is something like a bond, as is shown in Fig. 1b. This may be easily related to "line physics".

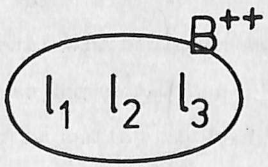

Fig. 1a

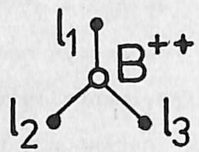

Fig. 1b

Any way, neutrino is supposed to become, through the loading of ε-charge, electron or muon, which is in a state different from that of neutrino and has its characteristic rest mass and Compton wave length. Leptons are then supposed to transit, through the loading of B^{++}, into states different from those of ordinary leptons, losing their original Compton wave length. Thus, the mechanism of these loadings is considered to be beyond the quantum mechanics at present. It is also supposed that the attaching of leptons to B^{++} saturates almost completely at three leptons, and any baryon

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*) Cf. M. Taketani, Prog. Theor. Phys. Suppl. No. 19 (1961), 10, items 21 and 36, for a detailed discussion of this point.

so generated does not act appreciable force on more leptons.

It may be said that the leptons which are assumed to be in baryon bear the character of the kinematics of baryon, while B^{++} bears the character of the dynamics of baryon. That is, B^{++} not only binds leptons (three leptons in the present case) together to generate baryon, but also becomes the source of meson field as the charge of strong interaction, through which there arises the self-energy giving the mass of baryon in addition.

Recently, there are many theoretical works in which urbaryons (including quarks) are assumed to have very small masses in their stable states in the interior of elementary particle. It may be said that from the viewpoint of model these works are close to our theory. That is, people are taking ideas very similar to our idea that urbaryon includes leptons or somethings like leptons which are bound together through B^{++}-matter (or charge).

As to the lepton τ recently discovered, it can be predicted from the neutrino unified theory that there are baryons generated from the attaching of B-matter onto three leptons including τ.

One can consider a new independent neutrino ν_τ corresponding to τ. Or, one can consider, for another possibility, that τ is generated on account of the difference in the state of attaching of ε-charge onto neutrino whose kind is restricted to ν_e and ν_μ only. This case matches with the consideration, said to be demanded from astrophysics, that the kinds of neutrino should not be too many if neutrinos are massless. It may be possible to make clear the nature of ν_τ and τ from that of the baryons corresponding to ν_τ and τ, respectively.

(iii) Quarks were introduced as the urbaryons with fractional charges. Now, leptons have been thought to be more elementary in general than baryons. We should consider the reason why leptons have not fractional charges. We can consider the following two cases:

(1) There exists no fractional charge.

(2) Any lepton is constituted from a combination of fractional charges of quark type.

If there exist fractional charges in the electric charge, the fractional charges should fundamentally be elemental electric charges. This case is therefore same as the case (2) given above. In this case, there arises the question why the leptons do not represent such fractional charges. One should then introduce for the leptons some structure due to the fractional charges. It may become natural, thus, to consider the lepton octet and so on.

If there are such lepton octet etc., it should be said that all the baryons can be deduced with the original Nagoya model.

If the electron and μ-meson are composed of fractional charges, the order of the agreement between the present quantum electrodynamics and experimental results should be taken into consideration.*)

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*) For the comparison of the quantum electrodynamics with the experimental result at present, see for example T. Kinoshita, Proc. 19th Intnat. Conf. High Energy Phys., Tokyo (1978), p.571.

It would mean an importnat condition to show at least such composition of the electron and μ-meson out of the fractional charges that is satisfactory with respect to the present order of this agreement.

This means more than the finding of satisfication in a simple assignment of different sets of quantum numbers for baryons and leptons, since this is related to the problem: what the fractional charges are.

(iv) These points mentioned above show that we should consider the problem of the level on which leptons are treated in comparison with baryons. If we take the viewpoint that leptons are treated more easily on the same level as urbaryons than they are treated in terms of the lepton octet on the same level as baryons, we see that the São Paulo model or the neutrino unified theory is natural to be thought about.

Considering from the famous words "Even the electron is inexhaustible" which Sakata quoted in his papers,[47] however, we should consider that the electron may naturally have some structure. Although at present there is a good agreement between the quantum electrodynamics of electron and the experimental results mentioned above, the energy range covered is not wide enough. Therefore, it may have a large possibility that the electron has an additive magnetic moment when the electron mass is deduced from the São Paulo model as will be discussed in §4 below. Furthermore, we may have to consider more complex structure for the neutrino. If leptons have such structure that include fractional charges, it will be necessary to think about and introduce the mechanism and the force which combine the parts having those fractional charges.

Baryon excited resonances are considered, in our model, to be the states arising from the attaching of various mesons onto the baryons.[25)] Discussions about how to consider excited meson levels will be given in the next section.

As to the baryon resonance, it has been said that the Tomonaga intermediate coupling theory[26)] and the Chew-Low theory[27)] succeeded in deriving the 3-3 resonance in pion-nucleon scattering. We generalized this way of thinking so as to consider that many baryon resonances are in general given by the intermediate coupling theoretical attaching of mesons onto baryons.[25),33)]

In this case, it is a problem how to consider the baryon decaplet. For this, there are two ways of thinking. One is the way of the present prevailing theory to consider that the baryon itself has the decaplet state. A way in this line of deducing the decaplet state in the neutrino unified theory was shown in Katayama and Taketani[24)]. The other is the way to consider that the decaplet state arises from the attaching of mesons onto baryons as in the case of the intermediate coupling of pion with nucleon giving rise to the 3-3 resonance. In this way of thinking, we may consider that

$$\Omega^- = \langle \Xi^0 + K^- \rangle$$

and the binding energy in this case is slightly positive in contrast to the case of the (3-3) resonance in π-p scattering.

In the latter case, it can be thought the group theoretical representation of the decaplet state does not mean the internal structure of the baryon resonances, but indicates the kinematics of the composite state of baryon and meson.

§3. On the boson

As to the boson, the Sakata model gave the first step of theorization. From the I.O.O. theory[29)] based on the original Sakata model, the boson octet was theoretically deduced and the η-meson was predicted before the experimental discovery. This was the first time when the concept of the octet state was introduced for hadrons, and the baryon octet state was introduced analogously to the boson octet.

In the original Sakata model, mesons are considered as the composite systems of a baryon and an anti-baryon, that is, $\langle N\bar{N} \rangle$ states. It is not always necessary to take the baryon here as the physical baryon. It can be the urbaryon.

When the fundamental baryon in the original Sakata model was considered further to be composed of three urbaryons, too, the model of meson became classified into two types. One is to consider that from the urbaryon q the meson is given by the $\langle q\bar{q}\rangle$ state. This is the way which is usually taken nowadays in the quark model. The other is to consider that the meson is given by the $\langle N\bar{N}\rangle$ state. In this latter case, because the baryon is considered to be composed of three urbaryons, i.e. $N(q_1, q_2, q_3)$, the meson is considered to be given by the state $\langle N(q_1, q_2, q_3), \overline{N(q_1, q_2, q_3)}\rangle$. We named the former model as the composite model of atomic type and the latter model as the composite model of molecular type.[30),31)]

Although the present-day quark model takes only the composite model of atomic type, the recently discovered di-proton state seems to indicate the possibility of the composite model of molecular type. The composite model of molecular type is more understandable in view of the spacial extension of meson. Furthermore, in the theory of nuclear force, the two pion exchange force and the three pion exchange force can be treated as one boson exchange forces, because the exchanged pions mutually resonate to form a boson such as ρ, ω, etc..[32)] It was shown that even if the exchanged pions do not resonate completely to form such a boson, the two and three pion exchange force can be treated fairly well in the one boson approximation[32)]. This fact shows that it is better to consider that bosons have rather complex structure and spacial extension. The representation $\langle q\bar{q}\rangle$ of bosons may rather be said to extract the kinematics of their composition.

About meson resonances and baryon resonances, we considered the possibility of the excited state of meson itself and of the

excited state of baryon due to the attaching of meson onto baryon.[25)] Nagasaki and Taketani[28),33)] tried a model to explain the meson resonances by treating them phenomenologically as the ones due to excitation of a matter field. This model is based on Tati's theory of hadronic matter[34)]. The level scheme of hadrons had been so far discussed from the viewpoint of kinematics. In our model, we gave instead a discusssion from the viewpoint of dynamics of the level scheme of meson resonances, separating their kinematical character.*)

To consider the meson as the state $\langle q\bar{q}\rangle$ may be said to make a pair of an urbaryon and an anti-urbaryon the representative of the meson, abstracting the kinematical nature of its composition in disregard of its complicated nature and structure such as mentioned above.

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*) In our work[33)] in 1970, we assumed that "the intrinsic spin and parity of the meson are given by the Sakata model, just as the angular momenta of the odd nucleons in A. Bohr's collective model of the nucleus are coupled to that of the collective motion", in treating the states of many pairs of N and $\bar{N}$ phenomenologically as the ones due to excitation of a matter field.

§4. H, SH and UH

In my pamphlet attached to Prog. Theor. Phys. Suppl. No. 54 (1973) mentioned in the previous sections, I thought that the H-quantum is the accumulative point of meson resonances, at which there is the transition point from the old physics to new physics.

Through the analyses of jet phenomena at ultra-high energies, the three kinds of quanta H, SH and UH and respective events belonging to them are classified. They have the characteristic energies of about 2 ~ 3 GeV, 20 GeV and 200 GeV, respectively, and the respective characteristic values of transverse momentum. About the H-quantum, although events corresponding to it are recently observed in accelerator experiments, they are called with the different name of "cluster", in disregard of the H-quantum and the jet events discovered in cosmic ray experiments.

It has been known also that it is very effective to analyze jet phenomena at higher accelerator energies with the notion of SH-quantum.[35),36)] Furthermore, at ultra-high energies, characteristic phenomena belonging to the UH-quantum have been made clear. It has turned out that there are two kinds of jet phenomena due to the decay of the UH-quantum. One is of the meson production type, and decays into numerous mesons. The other is the one which is called as the Centaurus type, and decays almost into many baryons. It is reported that these two types of the decay of UH-quantum are fairly well distinguished, and there is almost no

intermediate type in mixture of the both types.

Taketani and Nagasaki[37)] introduced the following rule, and calculated the decay of UH-quantum with the statistical theory.

Rule [A-1] The decay processes of UH-quantum into mesons and into baryons are completely distinguished.

Rule [A-2] The decay process of UH-quantum into mesons takes place stepwisely through SH- and H-quanta:

$$UH \rightarrow SH's \ , \quad SH \rightarrow H's \ , \quad H \rightarrow mesons \ .$$

The separation of the decay of UH-quantum of the Centaurus type from that of the meson production type is, in the statistical theory, due to the fact that the branching ratio of the decay of UH-quantum into baryons is very large compared with that into SH's on account of the large mass of SH compared with the baryon. It is therefore necessary for the decay of the meson production type to add further the following rules:

Rule [B-1] In the decay of UH-quantum, besides its statistical nature, there is a kind of continuity law of the decay into H-quantum series.

Rule [B-2] In the decay of SH-quantum, the same as [B-1] holds.

The rules mentioned above may have some relation to the problem of entropy change in the decays.[38)] It may be considered also that there are various kinds of the initial states of UH-quantum.

Jet phenomena with estimated values of energy around that of SH-quantum are observed also to make decay of the Centaurus type, and are called as the mini-Centaurus type. There discovered is a type of event named as the Geminion type, in which a decay into two "particles" takes place.

As is seen in other papers in the present issue, many results of the accelerator experiments on jet phenomena can be explained with the model of the production and two step decay of SH-quantum. Analyses of the experimental data with this model have been made by Aoyama University group[35] and by Rikkyo University group.[36]

About H-quantum, Hasegawa[39] got his idea from the structure of meson in the original Sakata model. Taketani and Fujimoto[40] considered that in a baryon-baryon collision, the pion cloud of the incoming baryon with a sufficient speed becomes thinner than the size of the structure of pion r_π because of the Lorentz contraction, to give a large impact on the structure $\langle N\bar{N} \rangle$ itself of the pion in the cloud of the target baryon, giving rise to the H-quantum production. With the Lorentz factor γ of the incoming baryon and the pion Compton wave length $\lambda\!\!\!^{-}_\pi$, a new mechanism to give rise to the H-quantum production works in this model when

$$\lambda\!\!\!^{-}_\pi/\gamma \lesssim r_\pi \quad .$$

Because the threshold energy of the H-quantum production is estimated to be about 10 GeV, we have

$$\gamma \sim \lambda\!\!\!^{-}_\pi/r_\pi \sim 10 \quad ,$$

and therefore

$$r_\pi \sim 10^{-14} \text{ cm} \quad .$$

Since in the original Sakata model the pion is composed of a baryon-antibaryon pair, r_π is considered to be of the order of the baryon Compton wave length $\lambda\!\!\!^{-}_{baryon}$ which is of the same order of magnitude as the Compton wave length of H-quantum $\lambda\!\!\!^{-}_H$:

$$r_\pi \sim \lambda\!\!\!^{-}_{baryon} \sim \lambda\!\!\!^{-}_H \quad .$$

The value for r_π given above is consistent with this relation.

SH-quantum has a mass of about 20 GeV, and is considered to be produced through some oscillation of urbaryons in a baryon. Therefore, the size of the structure of baryon is considered to be given by

$$r_{baryon} \sim \lambda\!\!\!^{-}_{urbaryon} \sim \lambda\!\!\!^{-}_{SH} \sim 10^{-15} \text{ cm} \quad .$$

Furthermore, UH-quantum has a mass of about 200 GeV, and is considered, for example, to be produced through some direct shock onto B^{++}-matter or urbaryon. If we consider that the UH-quantum represents some structure of urbaryon, the size of this structure may be considered to be given by

$$r_{urbaryon} \sim \lambda\!\!\!^{-}_{UH} \sim 10^{-16} \text{ cm} \quad .$$

In the above order estimations, the use is made of the idea of the Compton wave length. It is not clear, however, whether quantum mechanics is applicable to such regions as are discussed above. It should be mentioned that the idea of the Compton wave length is used here in the sprit of the correspondence principle.

§5. Weak interaction

At present, it is generally thought that the weak interaction is mediated by a weak boson. This is almost identical to the thought that is deduced from the application of the scheme of the theory of vector meson made by Yukawa et al. in 1938[41] to the case of the weak interaction.

The existence of the weak boson has not been proved experimentally yet.

On the basis of the São Paulo model in which the lepton is considered to be generated through the ε-charge attaching onto the neutrino, Katayama and Taketani[42] proposed in 1961 the mechanism of ε-charge transfer, in which the weak interaction is assumed to be generated through the transfer of ε-charge from one neutrino to another neutrino. This mechanism was extended by Kaneko[43] in 1975 to include the neutral current in the weak interaction which was known experimentally to exist. Aoki, Hayashi and Koike[44] discussed effects of heavy leptons in this line of consideration.

According to our way of consideration, the wave function of neutrino is not necessarily of two components.

The weak interaction has such a form of interaction that is not renormalizable as it stands. The present author therefore considered in 1957 that the weak interaction could not yet be weak at ultra-high energies.[45]

If the weak interaction would appear to be a strong interaction, it may be possible to consider the possibility that it would have some relation to the production of UH-quantum.

ε-charge, the transfer of which was considered in our model to give the weak interaction, is to generate the electromagnetic interaction. The electromagnetic interaction and the weak interaction are therefore unified in this model in their structure.

Furthermore, if we extend De Broglie's neutrino theory of light in the line of our model, we may consider that the electromagnetic field would be something like

$$A_\mu = (\overline{\varepsilon\psi})O_\mu(\varepsilon\psi) \quad .$$

This possibility was considered already in Taketani and Katayama.[42] Of course, in this way of consideration, there are difficulties as was shown in Ref. 42). This way of consideration aimes at, however, the unification of the electromagnetic interaction, the weak interaction and the neutrino problem in their structure.

§6. Conflict between matter and field and problem of selfenergy

"Conflict between matter and field" was one of the most important problems in which I was interested throughout the time of the World War II, and I thought that it would be one of the fundamental problems in the field theory of elementary particles.

In the quantum field theory, if we consider the coexistent system of electron and electromagnetic field, for example, we take their fields and the interaction between them, and quantize each of them. In this way, we have been able to get successful results for various problems. However, about the reaction of the electromagnetic field onto the electron due to its electric charge, and about the energy of the electron itself due to its interaction with the electromagnetic field, there remained essentially an unnaturality, leaving us infinite results. In order to solve this, Born proposed a unified theory resting on the electromagnetic field, advancing a theory in which the electron was given as the singularity in the electromagnetic field. This theory was able to deduce the electron mass quite naturally in the domain of the classical field theory. There was a difficulty, however, in the quantization of this field.

In my paper mentioned above, I analysed this difficulty as being due to the fundamentally contradicting two concepts of matter and field, in a similar way as in the case of the quantum mechanics in which the conflict between the concepts of particle and wave is unified. I considered that there should be a theory in future in which the conflict between the concepts of matter and field was unified. The difficulty of quantization in Born's theory arises directly from the problem of the non-linearity of

its equation which is one of important problems of the conflict between the concepts of matter and field, too. However, as a fundamental physical problem in a unified field theory, it is related to the fact that it is impossible to deduce fermion through the quantization of boson field, while it is possible to deduce boson from fermion field, as I pointed out in my paper. Any boson field gives us particle of zero or integer spin, but can not gives us any particle of half-integer spin. This fact is considered to be quite natural nowadays, but there was no body who pointed out it at that time. This fact is, however, most fundamental.

In the case of the electorn, it has one half spin, and is considered to be a matter particle on the basis of its electric charge. The electromagnetic field is considered, on the other hand, to be a field without electric charge. This relation is a typical example of "the conflict between matter and field".

As will be mentioned in the following, developments on this line of consideration were achieved by Sakata and his school and by us. These were the developments in the substantialistic stage about "the conflict between matter and field". They were made in the following three steps:

(1) The theory of mixed fields —— this was based on Sakata's methodology and was a theory of electron in terms of the C-meson.

(2) The composite model of elementary particles —— this was based on the aforementioned fact that fermions are not deduced from boson field through quantization while bosons can be deduced

from fermions through composition. There resulted the Sakata model as a unified theory of hadrons.

(3) The method of separating the interaction constants belonging to matter particles, that is to say the dynamics, from the kinematics of particles —— this gave rise to the Nagoya model and the São Paulo model.

Let us discuss these three points more in details.

(1) Shortly after the World War II, discussions were held on the problem of "the conflict between matter and field" between Sakata with his group and I myself. Sakata analysed this problem in the case of the electron with his method of mixed fields, arriving at the C-meson theory.

The C-meson theory was able to solve the difficulty of the infinite selfenergy of electron, but it could not overcome fundamentally the difficulty due to the "conflict between matter and field".

In general, the usual way taken to overcome the difficulty of the infinite selfenergy is the introduction of a length. This way of introducing a length has been tried in many theories, including Yukawa's nonlocal field theory.

The role played by the C-meson theory was to replace the introduction of a length with that of a particle with a mass. The first great success in the replacement of the introduction of a length with that of a particle with a mass was the Yukawa theory in which the problem of the nuclear force with a finite range was settled with the introduction of the meson with a mass. In the case of the C-meson theory, the far more purely theoretical problem of the classical electron radius was solved with the introduction of the C-meson with a mass.

Tomonaga, through the way of calculations in the line of the C-meson theory, arrived at the theory of renormalization. The Tomonaga theory of renormalization was able to remove the infinity in the selfenergy and that in the charge of the electromagnetic interaction. In the theory of renormalization, neither a characteristic length nor any particle with a characteristic mass is introduced. At the same time, however, in the theory of renormalization, the mass of electron itself can not be deduced from the electromagnetic interaction.

(2) As is mentioned in §2, the origin of Sakata's composite model traces back to our discussions on "conflict between matter and field". That is, the Sakata model was proposed in 1955 for baryons and hadrons, starting from the De Broglie theory of photon, on the basis of the theory of "conflict between matter and field", and passing the Fermi-Yang theory of pion.

(3) By the proposal of the Sakata model, it became able at first to note the B-L symmetry[15)] due to the parallelism between baryons and leptons. The Nagoya model[17)] was proposed in the line of further development of this symmetry. On assuming moreover the structure of leptons themselves due to the coupling of

neutrino and ε-charge, Katayama and Taketani[6] proposed the São Paulo model.

The fundamental aim of the São Paulo model is to clarify the origin of the rest mass of particle. That is, it aims at the deduction of the masses of the electron and muon from the massless neutrino with the loading of ε-charge. In other words, it aims at the deduction of the rest mass from an equation having only the terms of the electromagnetic and weak interactions without the mass term. This end can not be obtained with the ordinary interaction between electron and electromagnetic field, that is, with a renormalizable interaction. It was clear, therefore, that only an additional special interaction term of magnetic moment and the terms of weak interaction including various types can serve for it. They are all unrenormalizable. We were able to obtain a mass term by introducing a factor of length into such unrenormalizable interactions.[6),42)]

The equation in our neutrino unified theory is very similar to Heisenberg's fundamental equation.

In Ref.'s 6) and 42) mentioned just above, we took only one kind of neutrino. But, the same calculation can be applied of course to the case of two neutrinos. Although the present knowledge of the electromagnetic interaction is somewhat deeper than that around 1959 when Ref's 6) and 42) were worked, the essential point is not changed. It suffices only to take a

somewhat smaller value of the magnetic moment.[*)]

The contribution to the masses of electron and muon from the weak interaction is through baryons, and is obtained with the introduction of the weak interaction of the S, T and P types in addition to that of the V-A type.[**)] They can be adequately chosen in relation with the strength of the from factor of the interaction.

In our papers[6),42)] done in 1959, we derived the masses of electron and muon from the weak interaction by adjusting the form factor adequately, for the case of the complete polarization in which the mass of neutrino remains to be zero. In order to deduce

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*) In 6) and 42), we took 10^{-6} (in unit of the electron Bohr magneton) for the order of the magnetude of the additional Pauli term. This order should be lowered to 10^{-10} according to recent experimental data (cf. the footnote on p.11). The cutoff energy $\lambda \sim 10$ GeV taken in 6) and 39) to get the whole electron mass therefore becomes to be $\lambda \sim 10^3$ GeV, as was noted in 6).

**) For the limits on possible admixtures of the interactions of other types than the V-A type, see for example S. Wojcicki's lecture on weak decay, Proc. Summer Institute on Particle Physics, July 1978, SLAC Report No. 215, p.193, in which quoted are the limits $|g_S|$, $|g_T|$, $|g_P| \lesssim |g_V|/3$ taken from S. Darenzo, Phys. Rev. 181 (1969), 1854.

the mass for a heavier charged lepton such as τ-meson, we have to use a form factor with a radius smaller than that for the electron or muon*). In doing so, we are concerned with high frequency parts of the interaction, and then we are confronted with not only the electromagnetic interaction at high energies but also complex effects of the weak interaction at high energies. Especially, since the unrenormalizable interactions are taken to deduce the masses of leptons from the standpoint of the present paper, they will have great contributions there. Contributions from the strong interactions would also have some effects there.

At present, for the neutrino, ν_τ is accepted besides ν_e and ν_μ. It may be possible, developing a step further the thing mentioned on p.11 aobve, to deduce ν_e, ν_μ, ν_τ and other kind of neutrino, if any, altogether from the unified neutrinos. For

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*) As was shown in Ref. 6), the root-mean-square radius of the form factor $\sqrt{\langle r^2\rangle}$ for the muon should be about 1/14 times smaller than $\sqrt{\langle r^2\rangle}$ for the electron. Similarly, $\sqrt{\langle r^2\rangle}$ for the τ-meson would be about 1/4 times smaller than $\sqrt{\langle r^2\rangle}$ for the muon. With the order of the magnitude of the additional Pauli term 10^{-10} noted in the footnote on p.28, $\sqrt{\langle r^2\rangle}$ for the electron should be of the order of 10^{-16} cm, and $\sqrt{\langle r^2\rangle}$ for the τ-meson would be of the order of 10^{-17} cm, consistently with the cutoff energy noted in the same footnote.

example, it may be possible to consider a theory in which each of the neutrinos, ν_i's, is represented by a superposition of the unified neutrinos, ν_β's:

$$\nu_i = \sum_\beta a_{i\beta}\nu_\beta \quad .$$

This would mean that the neutrinos have some complex structures. For example, if the leptons are composed of a number of ur-leptons, there should of course be some relations among the neutrinos. And, if we take a non-local interaction, the neutrinos themselves would become non-local fields. It may be possible then that the neutrinos would not be completely polarized, and would have some masses.

In our theory[6),42)] mentioned above, we deduced the lepton mass from the baryon mass through the weak interaction. This can be said to give another support for the unified theory of the lepton and baryon.

In any way, as was mentioned in Ref. 6) and 42), it is impossible for other types of theories to show the foundation of the masses of e and μ, etc.. The Tomonaga theory of renormalization should be said therefore to be a phenomenological solution.

In order to make the weak interaction renormalizable, it is necessary to introduce another particle having a mass. This corresponds to the equivalence mentioned above of the introduction of a length with that of a particle having a mass. This in on the way that was pointed at first by the C-meson theory.

Another way of introducing the length is the non-local field theory proposed by Yukawa. Yukawa and Katayama[46] developed it and derived many freedoms in elementary particles.

I have been applying to the theory of elementary particles a philosophical methodology called as the three stage theory which I proposed many years before.[47] The concept of the substantialistic stage developed in the three stage theory was made effective just through its application to the theory of elementary particles begun with the Yukawa meson theory. After the World War II, the substantialistic way of introducing particles became so common that we have now the field called as particle physics. Such a situation represents just the success of this methodology.

The introduction of particle is not, however, the only thing that would be taken in the methodology of the three stage theory. The introduction of various particles easily for the purpose of increasing freedoms to get the fitting to experimental data or to improve the consistency of theory would rather be similar in its way to the introduction of various epicycles in Greek astronomy. It may be necessary to look back into the history that in the 19th century people made great efforts to know the nature of the "substance" called aether and finally had to abandon the concept of aether itself.

Acknowledgement

I would like to express my sincere thanks for interesting and valuable discussions, to the members of the research group of fire balls and particles in nuclear interactions at ultra-high energies, and to the members of the group of theoretical physics of Rikkyo University. My sincere thanks are also due to Prof. M. Nagasaki and Miss T. Ohsuga, secretary, Group of Theoretical Physics, Rikkyo University, for the preparation of the English version of my manuscript.

References

1) Prog. Theor. Phys. Suppl. No. 41 (1971); cf. Ref. 3) for a complete list of references.

2) Prog. Theor. Phys. Suppl. No. 54 (1973).

3) Cf. a review article by C. M. G. Lattes, Y. Fujimoto and S. Hasegawa, Phys. Report 65 (1980), 151.

4) M. Gell-Mann, Phys. Letters 8 (1964), 214; G. Zweig, CERN Preprints TH401, 412 (1964).

5) S. Sakata, Prog. Theor. Phys. 16 (1956), 686.

6) Y. Katayama, M. Taketani and J. L. Ferreira, Prog. Theor. Phys. 21 (1959), 818; J. L. Ferreira and Y. Katayama, ibid. 23 (1960), 776.

7) M. Taketani and Y. Katayama, Prog. Theor. Phys. 24 (1960), 661.

8) Discussion meeting held in Nov. 1945 at Dept. of Phys., Nagoya Univ. in evacuation at Fujimi.

9) Read at Colloquium on Nuclear Physics, May 1943, and published in Kagaku (Science) 16 (1946), 199 (in Japanese), and Prog. Theor. Phys. 2 (1947), 187.

10) Cf. S. Sakata, Prog. Theor. Phys. Suppl. No. 50 (1971), 98.

11) C. Møller and L. Rosenfeld, Det. Kgl. Danske Vidensk. Selsk. XVII (1940), 8.

12) S. Sakata and T. Inoue, Symposium on Meson Theory, Sep., 1943; Prog. Theor. Phys. 1 (1946), 143; included in Prog. Theor. Phys. Suppl. No. 1 (1955), 203.

13) L. de Broglie, C. R. Acad. Sci. Paris 195 (1932), 862.

14) E. Fermi and C. N. Yang, Phys. Rev. 76 (1949), 1111.

15) A. Gamba, R. E. Marshak and S. Okubo, Proc. Nat. Acad. Sci. 45 (1959), 881.

16) Proc. 9-th Intnat. Conf. on High Energy Nuclear Physics, Kiev (1959).

17) Z. Maki, M. Nakagawa, Y. Ohnuki and S. Sakata, Prog. Theor. Phys. 23 (1960), 1174.

18) Z. Maki, M. Nakagawa and S. Sakata, Prog. Theor. Phys. 28 (1962), 870.

19) Y. Katayama, K. Matumoto, S. Tanaka and E. Yamada, Prog. Theor. Phys. 28 (1962), 675.

20) N. Cabibbo, Phys. Rev. Letters 10 (1963), 531.

21) Z. Maki, Prog. Theor. Phys. 31 (1964), 331.

22) Z. Maki and Y. Ohnuki, Prog. Theor. Phys. 32 (1964), 144.

23) K. Niu, E. Mikumo and Y. Maeda, Prog. Theor. Phys. 46 (1971), 1644.

24) Y. Katayama and M. Taketani, Prog. Theor. Phys. 33 (1965), 1141.

25) M. Taketani, S. Nakamura, Y. Fujimoto, M. Nagasaki, S. Furuichi and S. Sato, Prog. Theor. Phys. Suppl. Nos. 37 & 38 (1966), 440.

26) Z. Maki, M. Sato and S. Tomonaga, Prog. Theor. Phys. 9 (1953), 607.

27) G. F. Chew and F. E. Low, Phys. Rev. 101 (1956), 1570.

28) M. Nagasaki and M. Taketani, Prog. Theor. Phys. Suppl. No. 54 (1973), 73.

29) M. Ikeda, S. Ogawa and Y. Ohnuki, Prog. Theor. Phys. 22 (1959), 715; 23 (1960), 1073.

30) M. Taketani, Symposium on Structure of Elementary Particles, Kobe, Dec. 2nd, 1964.

31) S. Sakata, Symposium on Comparison of High Energy Physics in Accelerator and Cosmic Energy Regions, Kyoto, Dec. 25th, 1964.

32) Cf. Prog. Theor. Phys. Suppl. No. 39 (1967).

33) M. Nagasaki and M. Taketani, Prog. Theor. Phys. 44 (1970), 1112.

34) T. Tati, Prog. Theor. Phys. Suppl. Nos. 37 & 38 (1966), 153; Prog. Theor. Phys. 43 (1970), 1596.

35) K. Yokoi, Proc. Intnat. Cosmic Ray Symp., Tokyo, 1974.

36) M. Hama, M. Nagasaki and H. Suzuki, Prog. Theor. Phys. 54 (1975), 795; 55 (1976), 1308; 57 (1977), 160; M. Hama and M. Nagasaki, ibid. 59 (1978), 1305.

37) M. Taketani and M. Nagasaki, Prog. Theor. Phys. 53 (1975), 1212.

38) M. Nagasaki, Research meeting on Nuclear Interactions at Ultra-High Energies, March 25 ~ 27, 1975, Research Institute for Fundamental Physics, Kyoto.

39) S. Hasegawa, Prog. Theor. Phys. 26 (1961), 151; 29 (1963), 128.

40) M. Taketani and Y. Fujimoto, Prog. Theor. Phys. Extra Number (1965), 651.

41) H. Yukawa, S. Sakata and M. Taketani, Proc. Phys. Math. Soc. Japan 20 (1938), 319; H. Yukawa, S. Sakata, M. Kobayashi and M. Taketani, ibid. 20 (1938), 720.

42) Y. Katayama and M. Taketani, Prog. Theor. Phys. Suppl. 19 (1961), 178, 189.

43) T. Kaneko, Prog. Theor. Phys. 53 (1975), 1196; 55 (1976), 1657, 1660.

44) M. Aoki, T. Hayashi and K. Koike, Lett. Nuovo Cim. 24 (1979), 505.

45) M. Taketani, Report at the Meeting of Phys. Soc. of Japan, Kanazawa, May 18, 1957.

46) Cf. Prog. Theor. Phys. Suppl. No. 41 (1968).

47) Cf. Prog. Theor. Phys. Suppl. No. 50 (1971).