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Remarks on the Unified Model of Elementary Particles

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

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

§ 1. Introduction and summary

In recent years, a considerable progress has been made in accumulationg detailed knowledge on the structure of interaction of elementary particles. Various kinds of excited particles have been discovered in succession, and the systematization of them from a unified point of view turns out to be an urgent problem of particle physics. In this connection, we can expect that the full-symmetry (or unitary-symmetry) theory of strong interactions would provide workable systematics as have been suggested by many authors.[1] On the other hand, if this programme of systematization will be successfully developed on the basis of e.g. the Sakata model,[2] we shall then meet with a more fundamental problem of unifying all elementary particles including both baryons and leptons into a unitary scheme, an example of which is a model proposed by the Nagoya group.[3] According to this model, the fundamental baryons p, n and Λ were supposed to be compound systems of leptons and a new sort of matter B^+:

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

Some important symmetry properties of particles such as the baryon-lepton (B-L) symmetry[3] and the full symmetry of strong interactions may be regarded as immediate consequences of this scheme. A crucial point is that the B-matter, the sole substance making leptons massive and active, is assumed to couple with leptons (not with antileptons) along the flow of leptonic weak current j_λ:

*) A similar proposal was made independently by the Kyoto group (Y. Katayama, K. Matumoto, S. Tanaka and E. Yamada Prog. Theor. Phys. **28** (1962), 675). See also C. Iso's work (preprint).

$$j_\lambda = (\bar{e}\,\nu)_\lambda + (\bar{\mu}\,\nu)_\lambda, \tag{1·1}$$

where $(\bar{a}b)_\lambda = (\bar{a}\gamma_\lambda(1+\gamma_5)b)$. The baryonic weak current J_λ is a B^+-loaded current $\langle j_\lambda \rangle_B$, i.e.

$$J_\lambda \equiv \langle j_\lambda \rangle_B = (\bar{n}p)_\lambda + c(\bar{\Lambda}p)_\lambda, \tag{1·2}$$

in which a correction factor $c(1/4\sim1/5)$ is to be attached in order to reproduce the low rate of strangeness violating leptonic decay of hyperons compared with usual ones.

It is, however, noted that, taking these fundamental postulates of B-matter for granted, all physical properties of B^+ might be reduced to an abstract operation which expresses merely one-to-one correspondence between baryons and leptons. In other words in so far as we confine our discussions within the frame work of these postulates, it seems difficult for us to find any clue to push forward our scheme to cover more involved properties of elementary particle interactions.

In this note, we shall therefore concentrate our attentions to some perplexing problems which might challenge the validity of fundamental ideas of our unified model. One of these problems is the possibility of the existence of two kinds of neutrinos,[4] one associates with electron and the other with muon. In § 2, we shall propose a way how to generalize the Nagoya model[3] under the two-neutrino hypothesis. Also of importance is the existence of weak interactions with $\Delta S/\Delta Q \neq 1$. Experimental results reported recently by Ely et al.[5] seem to suggest the existence of K_{e3} process with $\Delta S/\Delta Q = -1$:

$$K^0 \to \pi^+ + e^- + \bar{\nu}, \tag{1·3}$$

which is forbidden in the Nagoya model in its original form. In § 3, we shall suggest a possible explanation of occurrence of this type of processes and some bearings on the dynamical behaviour of the B-matter will be clarified.

§ 2. A possible unified model on the basis of two-neutrino hypotheses

2–1. *Definition of neutrinos and a modified baryon-lepton symmetry*

Let us first introduce two kinds of neutrinos ν_e and ν_μ into the leptonic weak current:

$$j_\lambda = (\bar{e}\,\nu_e)_\lambda + (\bar{\mu}\,\nu_\mu)_\lambda, \tag{2·1}$$

assuming that the weak interactions are described by the Hamiltonian of current-current type.[6] They are stable massless fermions unless other interactions are switched on. We may call them *the weak neutrinos.* The lepton numbers N_e and N_μ defined by

$$N_e = n_e + n_{\nu_e},\qquad N_\mu = n_\mu + n_{\nu_\mu} \tag{2·2}$$ *)

are conserved separately:

$$\Delta N_e = \Delta N_\mu = 0. \tag{2·3}$$

It should be stressed at this stage that the definition of the particle state of neutrino is quite arbitrary; we can speak of "neutrinos" which are different of weak neutrinos but expressed by the linear combinations of the latter. We assume that there exists a representation which defines *the true neutrinos* through some orthogonal transformation applied to the representation of weak neutrinos;

$$\left.\begin{aligned} \nu_1 &= \nu_e \cos\delta + \nu_\mu \sin\delta, \\ \nu_2 &= -\nu_e \sin\delta + \nu_\mu \cos\delta. \end{aligned}\right\} \quad (\delta: \text{real constant}) \tag{2·4}$$

Then, in terms of ν_1 and ν_2, (2·1) is expressed as

$$\begin{aligned} j_\lambda = (\bar{e}\,\nu_1)_\lambda \cos\delta + (\bar{\mu}\,\nu_1)_\lambda \sin\delta \\ - (\bar{e}\,\nu_2)_\lambda \sin\delta + (\bar{\mu}\,\nu_2)_\lambda \cos\delta. \end{aligned} \tag{2·1'}$$

It is conceivable to assume that the true neutrinos are basic particles together with e and μ from which corresponding baryons should be constructed along the line of the Nagoya model. Various models can be constructed in this way, but one of the most simple models may be given *under the postulate that the true neutrinos should be so defined that B^+ can be bound to ν_1 to form a proton but cannot be bound to ν_2*, symbolically

$$p = \langle B^+ \nu_1 \rangle, \quad n = \langle B^+ e^- \rangle, \quad \Lambda = \langle B^+ \mu^- \rangle, \tag{2·5}$$

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

$$J_\lambda \equiv \langle j_\lambda \rangle_B = (\bar{n}p)_\lambda \cos\delta + (\bar{\Lambda}p)_\lambda \sin\delta. \tag{2·6}$$

The weak interaction Hamiltonian is obviously

$$H_w = \frac{G}{\sqrt{2}} \mathcal{J}_\lambda \cdot \mathcal{J}_\lambda^{\,+}, \tag{2·7}$$

where

$$\mathcal{J}_\lambda = j_\lambda + \langle j_\lambda \rangle_B.$$

It is remarkable that the form of (2·6) is seen to be identical with that of a modified baryonic weak current suggested by Gell-Mann and Lévy[7]:

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*) n_a = the number of particle a − antiparticle $\bar{a}$.

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

$$J_\lambda = (\bar{n}p)_\lambda \frac{1}{\sqrt{1+\epsilon^2}} + (\bar{\Lambda}p)_\lambda \frac{\epsilon}{\sqrt{1+\epsilon^2}}, \tag{2·8}$$

in which the value of a parameter ϵ is to be chosen as $\sim 1/5$ so as to fit the slow rate of the leptonic decay of hyperons and, at the same time, to explain a subtle difference of G_V's between β- and μ-e decays.[8] Thus a formula which was given by purely phenomenological observation finds its physical ground in our unified model. It is worth noticing that the need of correction factor c in (1·2) or $\epsilon/\sqrt{1+\epsilon^2}$ in (2·8) seems to have been established also in the analysis of non-leptonic decays of K-mesons.[9]

There may arise some questions on our approach: (a) Is there any reason that ν_2 can do nothing with B^+? (b) Under what conditions should the parameter δ be determined? Though we have at present no answer to the first question, we should like only to mention that an analogous situation occurs also in the V-A interaction, where only the left-hand components of neutrino fields couple to other leptons. On the other hand, we may give some speculations about the problem (b), an example of which will be discussed in the following sub-section.

2–2. *Relation to the problem of mass difference between e and μ*

It is tempting to suppose that the question mentioned above may be closely connected with the problem of μ-e mass difference. Let us now start with bare leptons or *the urleptons* $\psi_0 = \begin{pmatrix} \mu_0 \\ e_0 \end{pmatrix}$ and $\varphi_0 = \begin{pmatrix} \nu_{\mu_0} \\ \nu_{e_0} \end{pmatrix}$, which have no mechanical masses. The leptonic weak current is to be defined by

$$j_\lambda = (\bar{\psi}_0 \varphi_0)_\lambda. \tag{2·9}$$

Assume that urleptons have an interaction with a new kind of field X having a large mass. For definiteness, we take an interaction of the form:

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

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

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

We suppose that the difference among four kinds of leptons should be produced by the interaction (2·10). That the condition (2·11) has a simple meaning is easily observed by making use of a representation for Λ and Λ' of the form

$$\Lambda = \begin{pmatrix} \eta_1^2 & \eta_1 \eta_2 \\ \eta_1 \eta_2 & \eta_2^2 \end{pmatrix}, \quad \Lambda' = \begin{pmatrix} \eta_1'^2 & \eta_1' \eta_2' \\ \eta_1' \eta_2' & \eta_2'^2 \end{pmatrix}, \tag{2·12}$$

where η's are real constants. To take an intrinsic difference between ψ_0 and φ_0 into account, we choose specifically

$$\eta_1' = \eta_2' \equiv \eta', \tag{2·13}$$

and regard η' to be very small (but not zero!). It is trivial to see that our system can be diagonalized in terms of new fields defined by the transformation:

$$\left.\begin{aligned} &\psi_0 \to \psi = \begin{pmatrix} \mu \\ e \end{pmatrix}, \\ &\mu = \frac{1}{\sqrt{\eta_1^2+\eta_2^2}}(\eta_1\,\mu_0 + \eta_2\, e_0), \\ &e = \frac{-1}{\sqrt{\eta_1^2+\eta_2^2}}(\eta_2\,\mu_0 - \eta_1\, e_0), \end{aligned}\right\} \tag{2·14a}$$

and

$$\left.\begin{aligned} &\varphi_0 \to \varphi = \begin{pmatrix} \nu_2 \\ \nu_1 \end{pmatrix}, \\ &\nu_2 = \frac{1}{\sqrt{2}}\,(\nu_{\mu 0} + \nu_{e0}), \\ &\nu_1 = \frac{-1}{\sqrt{2}}\,(\nu_{\mu 0} - \nu_{e0}). \end{aligned}\right\} \tag{2·14b}$$

The new particle states ψ and φ may be called *the true leptons* corresponding to the arguments in *2–1*, since they are stable against the interaction (2·10) which can be re-expressed as

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

Let us fix the value of η_1, η_2 and η'. In the first place, $\eta_1^2+\eta_2^2$ is determined by the condition that the observed mass of muon is identified with the self energy due to the interaction (2·10'). The ratio η_1/η_2 is obtained as follows. Introduce an "angle" δ by the relation:

$$\cos\left(\frac{\pi}{4}+\delta\right) = \eta_1/\sqrt{\eta_1^2+\eta_2^2}, \tag{2·15}$$

then the leptonic weak current (2·9) defined primarily in terms of urlepton fields takes the same form with (2·1') when use is made of true lepton fields. η_1/η_2 is then determined to fit the value of δ, i.e. $\sin\delta = 1/4 \sim 1/5$ as is expected from experimental observations. In the above arguments the form X^*X is not essential, but the renormalization factor Z_2 appearing in the μ and ν_2 fields must be almost equal to 1 in order that the universality of weak interactions is maintained. The form X^*X is preferable in this respect when we pre-suppose a use of the lowest order perturbation for this interaction. In this approximation it is interesting to note that if we fix the magnitudes of η_1 and η_2 in such a way that the diagonal parts of the self-energies or the "masses" of e_0 and μ_0 take, in Nambu's unit $(=\alpha^{-1}m_e)$, the values 1/2 and 1 respectively, we have

$$m_{\mu}=1+1/2=3/2\approx206m_e \tag{2·16}$$

and

$$\sin\delta\cdot\cos\delta\approx-1/6, \tag{2·17}$$

both of which correspond to the actual situations. Finally, we would like to add remarks on some characteristic properties of leptons in our scheme.

a) The weak neutrinos must be re-defined by a relation

$$\left.\begin{aligned}\nu_e&=\nu_1\cos\delta-\nu_2\sin\delta,\\ \nu_\mu&=\nu_1\sin\delta+\nu_2\cos\delta.\end{aligned}\right\} \tag{2·18}$$

The leptonic weak current (2·9) turns out to be of the same form with (2·1). In the present case, however, weak neutrinos are *not stable* due to the occurrence of a virtual transmutation $\nu_e\rightleftarrows\nu_\mu$ induced by the interaction (2·10). If the mass difference between ν_2 and ν_1, i.e. $|m_{\nu_2}-m_{\nu_1}|=m_{\nu_2}$*) is assumed to be a few Mev, the transmutation time $T(\nu_e\rightleftarrows\nu_\mu)$ becomes $\sim10^{-18}$ sec for fast neutrinos with a momentum of $\sim$Bev/c. Therefore, a chain of reactions such as[10)]

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

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

is useful to check the two-neutrino hypothesis only when $|m_{\nu_2}-m_{\nu_1}|\lesssim10^{-6}$ Mev under a conventional geometry of experiments. Conversely, the absence of e^- in the reaction (2·19b) will be able not only to verify the two-neutrino hypothesis but also to provide an upper limit of the mass of the second neutrino (ν_2) if the present scheme should be accepted.

b) As a result of the interaction (2·10), the decay $\mu\rightarrow e+\gamma$ could occur even if we do not assume intermediary bosons.[4)] But the rate of this decay is expected to be too small to detect because of the smallness of η' and m_{ν_2}. The search for this decay mode would become more and more important to test any attempts at the μ-e problem.

§ 3. A possible mechanism of decay processes with $\Delta S/\Delta Q\neq1$

3–1. *Allowed and forbidden transfer of the B-matter*

The baryonic weak current (1·2) or (2·6) leads us to the selection rule $\Delta S/\Delta Q=+1$. This comes from the assumption that the B-matter can never transfer from one basic lepton to another. As was mentioned in § 1, there seems to be some evidence of the existence of processes violating the $\Delta S/\Delta Q=+1$ rule. In order to overcome this difficulty, it would be necessary to generalize the original scheme of weak interaction based on the Sakata model so as to

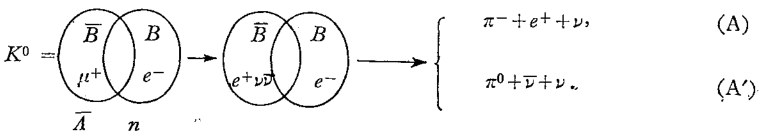
*) $m_{\nu1}=m_e=0$ in our scheme.

allow these processes in some way.*) Here, we will suggest a possible mechanism of such a process by introducing a new set of principles by which the behaviours of the B-matter will be described.[12]

As a preliminary consideration, it would be instructive to describe schematically how the ordinary K_{e3} processes with $\Delta S/\Delta Q=+1$, e.g.

$$K^0 \rightarrow \pi^- + e^+ + \nu, \qquad \text{(A)}$$

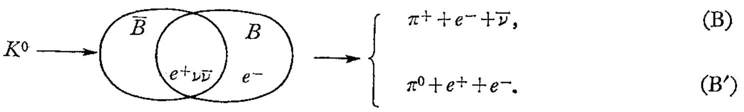
take place. This occurs through an intermediate stage shown in the following diagram:



The process (A') appears if $\bar{B}$ (anti-B) could transfer from a weak current vertex $(\bar{\mu}\nu)_\lambda$ to the other one, i.e. $(\bar{e}\nu)_\lambda$. We may call this type of transfer *the leap*. On the other hand, the process with $\Delta S/\Delta Q=-1$, e.g.

$$K^0 \rightarrow \pi^+ + e^- + \bar{\nu} \qquad \text{(B)}$$

occurs through another type of transfer of the B-matter:



Namely, the process (B) takes place as the crossing effect of an interchange of leptons

$$\nu + \langle e^- B\rangle \rightarrow \langle B\nu\rangle + e^- \qquad (3\cdot 1)$$

and of a leap of the B-matter. (3·1) means *a jump* of the B-matter from one lepton to the other. The process (B′) takes place, in contrast with (A′) and (B), by an act of the jump such as (3·1). It is, however, noticed that the both type of transfers should not occur by itself, since a leap induces the process $\mu^- + p \rightarrow e^- + p$ and a jump implies the reaction $\mu^- + n \rightarrow e^- + \Lambda$. Clearly, these processes should be forbidden. But there remains a possibility of admitting the process (B) by restricting the transfer of B^+ to be subjected to the following rules.

Rule (I): B^+ cannot leap but can jump being induced by another B-matter which is present in the baryonic weak current (*hypothesis of induced jump*).

This rule is essentially equivalent to the above developed arguments, the

*) A generalization along this line has been attempted also by Taketani from somewhat different point of view.[11]

result of which may be stated in the rule (I′): Only the simultaneous transfer of B's, of which one is a leap and the other is a jump at the same weak vertex, should be allowed to occur.

It would be natural to suppose that there enters a damping factor P in the matrix element of induced jump interactions, because this type of interactions differs from an ordinary one in that it depends critically on the structure of compound system. Roughly speaking, the factor P represents, for example, a measure of overlapping of baryon and anti-baryon in the composite particles under consideration. The magnitude of P in the process (B) can be estimated to fit the experimental results reported by Ely et al.[5] If we work with the two neutrino scheme proposed in the last section, we obtain

$$P/\sin\delta=(0.3\sim0.5)\,. \tag{3·2}$$

As we have shown that $\sin\delta\sim1/5$, P may be seen of the order of one tenth.

Under the rule (I) or (I′), the following processes would be allowed with probabilities of the same order as (B)

$$\left.\begin{aligned}&K^{+,0}\to\pi^{+,0}+\mu^{+}+e^{-},\\&K^{+,0}\to\pi^{+,0}+\bar{\nu}_\mu+\nu_e.\end{aligned}\right\}\qquad (\mathrm{C})^{*)}$$

The former could be easily detected in the decay mode $\tau^+\to2\pi^++\pi^-$ if it should really exist. But an essential difference between (B) and (C) is that in the former the induced jump is made from e^- to μ^-, whereas in the latter it occurs between ν_e and μ^-. Therefore, if it becomes clear that the processes (C) are highly suppressed, we must further add the rule (II): There should be no induced jump between (μ, e)- and (ν_μ, ν_e)-families. This rule would not be logically unacceptable since the magnitude of damping factor P may depends on the basic particles between which the induded jump occurs. An alternative rule for (II) can also be formulated in the rule (II′): The jump between leptons of the same family should be forbidden.

We have thus set up the rule (I, II) or (I′, II′) for admitting the transfer of B^+ so as to reproduce the weak interaction with the $\Delta S/\Delta Q=-1$ rule as a minimal extention of the B-L symmetry. We shall make here no attempts at clarifying a theoretical ground of these rules since this seems to us too premature a task at the pressent stage of the elementary particle physics.

3–2. *Effective six-fermion interaction*

To summarize the results to be expected from the rule (I, II) or (I′, II′) discussed in the above sub-section, it is convenient to write down the effective six-fermion interactions which can be uniquely determined by our rules. In general, these interactions would become non-local ones and be represented by

*) Note that the processes $K^{+,0}\to\pi^{+,0}+\mu^-(\nu_\mu)+e^+(\bar{\nu}_e)$ are forbidden in the present scheme.

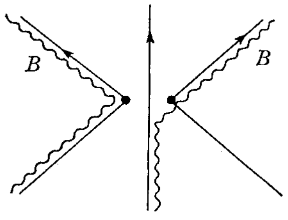


Fig. a. (Rule I, II)

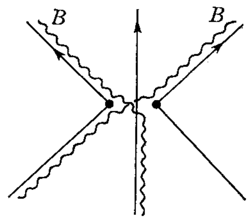


Fig. b. (Rule I′, II′)

the diagram in Fig. a or b, in which the solid lines correspond to the basic leptons and the pair of vertex points is a weak interaction of the form $j_\lambda \cdot j_\lambda^+$. From either set of these rules, we obtain the following interactions for each type of leptonic weak vertices:

$$\left.\begin{aligned}
(\bar{\nu}_e e)_\lambda \cdot (\bar{e}\nu_e)_\lambda \to & (\bar{p}n)(\bar{e}p)(\bar{p}\nu_e) + \frac{\varepsilon}{\sqrt{1+\varepsilon^2}}(\bar{p}n)(\bar{e}p)(\bar{p}\nu_\mu) \\
& + (\bar{p}n)(\bar{n}\nu_e)(\bar{e}n) + (\bar{p}n)(\bar{n}\nu_e)(\bar{\mu}\Lambda), \\
(\bar{\nu}_e e)_\lambda \cdot (\bar{\mu}\nu_\mu)_\lambda \to & \frac{\varepsilon}{\sqrt{1+\varepsilon^2}}(\bar{p}n)(\bar{\mu}p)(\bar{p}\nu_e) + \frac{\varepsilon^2}{1+\varepsilon^2}(\bar{p}n)(\bar{\mu}p)(\bar{p}\nu_\mu) \\
& + (\bar{p}n)(\bar{\Lambda}\nu_\mu)(\bar{e}n) + (\bar{p}n)(\bar{\Lambda}\nu_\mu)(\bar{\mu}\Lambda) + \\
& + \frac{\varepsilon}{\sqrt{1+\varepsilon^2}}(\bar{p}e)(\bar{\Lambda}p)(\bar{\nu}_e p) + \frac{\varepsilon^2}{1+\varepsilon^2}(\bar{p}e)(\bar{\Lambda}p)(\bar{\nu}_\mu p) \\
& + \frac{\varepsilon}{\sqrt{1+\varepsilon^2}}(\bar{\nu}_e n)(\bar{\Lambda}p)(\bar{n}e) + \frac{\varepsilon}{\sqrt{1+\varepsilon^2}}(\bar{\nu}_e n)(\bar{\Lambda}p)(\bar{\Lambda}\mu), \\
(\bar{\nu}_\mu \mu)_\lambda \cdot (\bar{\mu}\nu_\mu)_\lambda \to & \frac{\varepsilon}{\sqrt{1+\varepsilon^2}}\Big[\frac{\varepsilon}{\sqrt{1+\varepsilon^2}}(\bar{p}\Lambda)(\bar{\mu}p)(\bar{p}\nu_e) \\
& + \frac{\varepsilon^2}{1+\varepsilon^2}(\bar{p}\Lambda)(\bar{\mu}p)(\bar{p}\nu_\mu) + (\bar{p}\Lambda)(\bar{\Lambda}\nu_\mu)(\bar{e}n) \\
& + (\bar{p}\Lambda)(\bar{\Lambda}\nu_\mu)(\bar{\mu}\Lambda)\Big],
\end{aligned}\right\} \qquad (3\cdot3)$$

together with their hermitian conjugate, where we put $\sin\delta = \varepsilon/\sqrt{1+\varepsilon^2}$. $(\bar{a}b)(\bar{c}d)(\bar{e}f)$ is a scalar or pseudo-scalar product of fields and the parentheses show that the basic lepton involved is a connected line with or without a weak vertex point, the transformation properties of each quadratic being left undeter mined.

There is, however, a complex situation that the form of interactions obtained in $(3\cdot3)$ can not be taken too literally, because a part of the effective four-body interactions extracted from $(3\cdot3)$ should be considered as being absorbed, in some way, into the original four-body interactions satisfying *B-L* symmetry; otherwise we would meet with terms which destroy the success of *V-A* theory.

3–3. *Some predictions*

In spite of these circumstances, it is possible to some extent to discuss the related problems of weak interactions along the course of the present approach.

The first point we want to remark is the process

$$K^0 \to \pi^+ + \mu^- + \bar{\nu}_\mu \tag{D}$$

which is considered to be a counter part of the process (B). In our scheme μ-processes with $\Delta S/\Delta Q = -1$ should be forbidden in the lowest order of weak interactions. This is because that these processes involve, in the sense of Nagoya model, the transition $\mu^+ \leftrightarrow \mu^-$ (or $\Delta n_\mu = 2$) excluded in the first order weak process. At present, there seems to be no evidence for the existence of the process (D).[5),*)] In any way, this process would provide an important clue to the development of our scheme.

It is also interesting to note that the process

$$K^+ \to \overline{K}^0 + \mu^+ + \nu_e \tag{E}$$

which obeys a relation $\Delta S/\Delta Q = +2$ is allowed to occur according to our rule (I, II) or equivalently (I′, II′).[**)] A direct check on the presence of (E) can be made by observing the processes

$$\left.\begin{aligned} &\Xi^- \to n + \mu^- + \bar{\nu}_e, \\ &\Xi^0 \to p + \mu^- + \bar{\nu}_e. \end{aligned}\right\} \tag{E′}$$

But the factor $\varepsilon/\sqrt{1+\varepsilon^2}$ associated with these processes (see (3·3)) makes them less frequent as compared with, e.g. (B).

We have described in this note a possible way to generalize the foregoing series of approach[2),3)] that intend to clarify a deeper connection among elementary particles. Attentions were mainly concentrated on the structure of weak interactions, since the experimental materials being accumulated in this field seem to be of quite importance to reveal more fundamental structure of matter. The scheme proposed here is naturally of qualitative nature and moreover many problems are left to be settled in the course of a future development of the theory.

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*) Recently an evidence has been reported for the existence of the μ^+-decay mode of Σ-particle (Phys. Rev. Letters **9** (1962)). Although the experimental statistics is now rather poor, determination of the rate of this process will provide us with further clues for clarifying the structure of Σ-particle and of its weak interactions. A possible explanation of the occurrence of this process is now being examined along this line of thought.

**) We are grateful to Dr. Y. Ohnuki for his discussion on this point.

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References

1) M. Ikeda, S. Ogawa and Y. Ohnuki, Prog. Theor. Phys. Suppl. No. **19** (1961), 44.
K. Matumoto, S. Sawada, Y. Sumi and M. Yonezawa, Prog. Theor. Phys. Suppl. No. 19 (1961), 66. Other references including their original articles will be found in this volume. See also M. Gell-Mann, preprint. Y. Ohnuki, S. Otsuki and Y. Sumi, preprint.
2) S. Sakata, Prog. Theor. Phys. **16** (1956), 686.
3) Z. Maki, M. Nakagawa, Y. Ohnuki and S. Sakata, Prog. Theor. Phys. **23** (1960), 1274.
A. Gamba, R. E. Marshak and S. Okubo, Proc. Natl. Acad. Sci. **45** (1959), 881.
See also Prog. Theor. Phys. Suppl. No. **19** (1961), Part III, where the neutrino unified model proposed by Taketani et al. is found recapitulated.
4) A prototype of two neutrino theory was first proposed by S. Sakata and T. Inoue (Prog. Theor. Phys. **1** (1946), 143). See also J. Schwinger, Ann. Phys. **2** (1957), 407.
K. Nishijima, Phys. Rev. **108** (1958), 907.
M. Konuma, Nucl. Phys. **5** (1958), 504.
I. Kawakami, Prog. Theor. Phys. **19** (1958), 459.
B. Pontecorvo, JETP (USSR) **37** (1959), 1751.
S. Oneda and J. C. Pati, Phys. Rev. Letters **2** (1959), 125.
T. D. Lee and C. N. Yang, Phys. Rev. **119** (1960), 1410.
5) R. P. Ely et al., Phys. Rev. Letters 8 (1962), 132.
G. Alexander et al., UCRL-10173 (B. C. Maglić, lecture at Kyoto 16 May, 1962).
6) R. P. Feynman and M. Gell-Mann, Phys. Rev. **109** (1958), 193.
7) M. Gell-Mann and M. Lévy, Nuovo Cimento **10** (1960), 705.
8) R. P. Feynman, *Proceedings of the 10th Conference on High Energy Physics at Rochester* (1960), p. 501.
R. J. Blin-Stoyle and J. Le Tourex, Phys. Rev. **123** (1961), 627.
9) M. Nakagawa and S. Oneda, Prog. Theor. Phys. Suppl. No. **19** (1961), 125.
J. M. Dobbs et al., Phys. Rev. Letters 8 (1962), 295.
M. Nakagawa and S. Oneda, lecture at the INS symposium on June 7, 1962.
10) Such an experiment is said to be being performed at Brookhaven (private communication by C. Iso).
11) M. Taketani, Prog. Theor. Phys. Suppl No. **19** (1961).
M. Taketani and T. Tati, Prog. Theor. Phys. **28** (1962), 757.
12) S. Sakata, lecture at the Nagoya meeting on "the Models of Elementary Particles" held in Nov. 1961.