1. Toward a New Concept of Elementary Particles

Shoichi SAKATA

Institute for Theoretical Physics, Nagoya University, Nagoya

The universe is not to be narrowed down to the limits of the understanding, which has been men's practice up to now, but the understanding must be stretched and enlarged to take in the image of the universe as it is discovered.

FRANCIS BACON, Parasceve, Aphorism 4

1. In this issue, we wish to give a systematic survey of papers that have been published by Japanese physicists who adopted a new point of view toward the concept of elementary particles. In contrast to the current view that the elementary particles are the ultimate building stones of matter, we believe that nature as a whole has a structure of inexhaustible depth, and each of the different kinds of atomistic conceptions, such as molecule, atom, nucleus, elementary particle, and so forth, stands for each of the qualitatively different levels of matter disclosed one after another by deeper studies. We should never expect to find out the deepest level of matter, because there are certainly more elements in it than we can possibly be aware of at any particular stage of scientific development. Also we should never regard the field theory of elementary particles as the final theory of matter, because qualitatively new laws might be found at new levels.

The current view of the elementary particle arose firstly from the misbelief in unlimited validity of the present theory, in which it is assumed to be a mathematical point described by a local field. It was only an approximation to reality at a particular stage of our knowledge to assume that the elementary particles were structureless and occupied no space at all. But, with a great success of the field theory based on the point model, the majority of physicists became to believe that the elementary particles were the deepest level in the structure of matter, because a mathematical point is certainly indivisible. Later on, in order to get rid of the divergence difficulties that appeared in the present theory, many attempts were made to modify the point model by introducing the so-called “universal length” or “cutoff factor”. Nevertheless, the misbelief that the elementary particles were the deepest level of matter, and the dynamical laws which govern this level were the final theory of matter, has scarcely been doubted so far.
The second reason why the word structure of an elementary particle seemed criminal to most physicists would have been a widespread popularity of the positivist doctrine among them. It is well known that the logic of the present theory has a dualistic structure composed of the following two stages. In the first place, a hypothesis concerning the model of the objects is postulated, with considerations such as what sorts of particles exist in nature, and what sorts of interactions they are subject to, and so forth. Next comes the stage in which the quantization is applied to the system. The importance of recognizing such a dualistic structure was correctly stated by Bohr in his principle of correspondence, but the presence of the first stage has often been ignored or completely rejected by most physicists as a result of their positivistic attitude to consider that the role of the theory was merely to be a mathematical tool to calculate the probabilistic relationships among various observations.*

So far as we remain in the domain of applicability of the present theory, it is merely a matter of taste what sort of view one may take. But, as the limit of its applicability comes into question, the one-sidedness of the current view becomes clear.

It was first pointed out by Bohr in 1930 that there were certainly two questions which could not be answered by the present theory. They were the questions of predicting the numerical values of two dimensionless constants: the ratio between masses of the electron and of the proton, and the fine-structure constant $e^2/\hbar c$. If we take into account a great achievement in physics during the last thirty years, in which various sorts of elementary particles were found, they should be replaced with the mass spectrum of the elementary particles, and the structure of interactions. More strictly speaking, they are the questions of what sorts of elementary particles exist in nature, and what are the strength, the type and the symmetry of interactions among them.

In so far as we adopt the current view that the elementary particles are the ultimate building stones of matter, phenomenological forms of mass spectrum and of interactions should be regarded as the Providence of God, which would never be explained by the logic of matter, because they were introduced in the theory at its first stage as ad hoc assumptions concerning the model of objects. In other words, the current viewpoint will introduce religious elements into the science just as the Pythagorean school did in the Greek science, and stop the scientific thinking at that stage.**

* The importance of the first stage was more clearly stated by Take'cani in his pioneer work on the interpretation of quantum mechanics, which has been the philosophical background among us during the last quarter of the century (M. Take'cani, Problems of the Dialectic, Rironsha, Tokyo, 1946; see also S. Sakata, Kagaku, 29 (1959), 626).

** In fact, variant types of the symmetry models have been proposed up to the present in the spirit of Pythagoreans, who attached moral and aesthetic values to mathematical relations.
On the contrary, if we take the new point of view toward the concept of elementary particles, then it becomes possible to seek for the *causa formalis* of such elements step by step in the inexhaustible structure of matter. Our standpoint may be compared to that of the Ionian naturalists in Greek science who ever fought against the mythological understandings of nature.

As is well known, Heisenberg is attempting to search for the *causa formalis* of them in different modes of one and the same fundamental substance satisfying a nonlinear spinor equation of special symmetry. Nevertheless, his standpoint is essentially different from that of ours, because he believes that the fundamental substance is the deepest level of matter, and the form of his nonlinear equation is given by the *Providence of God*, just as Plato believed that God created the atoms of earth, fire, air and water from the fundamental substance as cube, tetrahedron, octahedron and icosahedron respectively.

2. In recent years, there has been rapid advance in our experimental knowledge concerning the interactions among various sorts of elementary particles. In the present issue, we attempt to understand the phenomenological forms of interactions step by step in terms of the inexhaustible level structure of matter. In other words, we try to disclose the deeper levels of matter one after another by seeking for the *causa formalis* of the phenomenological structure of interactions.

As for the strong interactions, a beautiful selection rule was found by Nakano and Nishijima and by Gell-Mann based on the concepts of the charge independence and the strangeness conservation. So far as the current viewpoint is adopted, this rule is regarded as the principle of the heaven given by the *Providence of God*. But if one is to take a correct viewpoint, its physical foundation should be sought in the deeper level of matter.

Along this line of thought, I proposed in 1955 a composite model of hyperons and mesons. By assuming a proton, a neutron and a lambda particle to be fundamental particles, and the other hyperons and mesons to be composed of these particles and their antiparticles, I succeeded in finding out the *causa formalis* of Nakano-Nishijima-Gell-Mann rule in the logic of matter. Moreover the mysterious concept of strangeness conservation was understood in a naturalistic term as the conservation of lambda particles.

The composite theory of hyperons and mesons was developed after a close analogy with the theory of nuclei, because the composite particles took the same rank as the nuclei in the hierarchy of infinite level structure of matter as is shown in the following diagram:

```
  molecule ---- atoms ----{ nuclei 
                      hypernuclei 
                       composite particles }
                       fundamental particles
```

--- molecules --- atoms ---{ nuclei 
                      hypernuclei 
                       composite particles }
                       fundamental particles
In the history of nuclear theory, it was most exciting that Ivanenko and Heisenberg showed a correct way how to explain the mysterious properties of nuclei. In 1932, just after the discovery of the neutron, they proposed a new model of nuclei in which neutrons and protons were assumed to be fundamental constituents. Before the advent of this model, most theoretical physicists were very pessimistic to develop the theory of nuclei. It was my primary desire that our composite model would play such a brilliant rôle in the theory of hyperons and mesons.

In accordance with this programme, Matumoto proposed a mass formula of the composite particles, which was the counterpart of Weizsäcker's formula for the mass defect of nuclei. It was rather surprising that though his formula was derived from a simple and bold assumption having no foundation in the current field theory at all, it not only reproduced the observed masses fairly well but also predicted some unknown particles.

Next, a field theoretical approach to our model was done by Maki, who showed how $\pi$-mesons could be formed from the fundamental particles. His work may be compared to the deuteron problem in the nuclear theory, but we must always be aware of the fact that the dynamical law which governs the interior of composite particles would be quite different from that of the current field theory. The field theoretical approach should therefore be understood in the spirit of the correspondence principle.

A considerable progress in the theory of composite particles was made by the use of a group-theoretical method based on an assumption of full symmetry among three fundamental particles. The concept of full symmetry was introduced by Ogawa, and independently by Klein, as a natural generalization of charge independence. Ikeda, Ohnuki and Ogawa studied the mathematical structure of full-symmetrical group, and developed a group-theoretical approach to the theory of composite particles. The main results obtained from this approach were the prediction of various resonance states like $K^*$ or $Y^*$ found in the scattering experiments. By revising Matumoto's mass formula, Sawada and Yonezawa calculated the energy values of the resonance states which gave remarkable agreements with experiments. Moreover, it should be stressed that a new particle $\pi_0'$ predicted from our theory seemed to play an important rôle in $K_{\ell 3}$ decay.

From these results it is expected that the scattering problems can also be treated by the analogy of nuclear reactions. Especially, I am tempted to think that the mystery of very high energy collisions will be solved along this line.

Now let us turn our attention to the weak interactions. According to Feynman and Gell-Mann, the phenomenological structure of weak interactions takes a form of current-current interaction like $J^\alpha \cdot J^\beta$, where $J^\alpha$ means the sum of charge-exchange $V-A$ currents belonging to baryons, mesons and leptons. If we adopt the viewpoint of the composite model, the baryon-meson
part of the Feynman-Gell-Mann current is reduced to a simplified form composed of \((p, n)\) and \((p, A)\) currents only. It is amusing that this simplified form of the current satisfies all the rules that have been required from experimental findings. In the first place, we get a selection rule like \(\Delta S = 0, \pm 1\), excluding \(\Delta S / \Delta Q = -1\), which seems to hold in the decays of baryons and mesons. Secondly, the conservation law for the vector part of the Feynman-Gell-Mann current, which has been assumed in order to account for the exact equality between the Fermi coupling constant of the \(\beta\)-decay and that of the \(\mu\)-decay, automatically comes out of this view. Furthermore, Ohnuki has recently proved that the axial vector current derived from the composite model justifies the calculation of Goldberger and Treiman\(^{13}\) of the lifetime of the \(\pi\)-meson in a natural way, without introducing a new assumption like that of Gell-Mann and Lévy.\(^{14}\)

If the composite theory of hyperons and mesons turns out to be correct, one may further imagine whether there exists some relation between the baryon triplet \((p, n, A)\) and the lepton triplet \((\nu, e, \mu)\). In fact, it was pointed out by Marshak\(^{15}\) at Kiev Conference that the phenomenological structure of weak interactions is symmetric with respect to the following interchanges among these triplets:

\[
\begin{array}{ccc}
p & n & A \\
\downarrow & \downarrow & \uparrow \\
\nu & e & \mu
\end{array}
\]

So far as we take the Kiev Symmetry of weak interactions seriously, one should have to seek for its \textit{causa formalis} in the deeper levels of matter as mentioned before. In addition to the Kiev Symmetry the full symmetry among the baryon triplet could also afford a clue to going another step in the deeper structure of matter.

The Nagoya group\(^{16}\) proposed in 1959 a new model which can account for these symmetries in naturalistic terms. According to the Nagoya model, the lepton triplet is regarded as basic particles, from which the baryon triplet is generated by smearing them with some sort of positively charged, point-like substance called \(B\)-matter. We may denote these relations as follows:

\[
p = \langle B^+, \nu \rangle, \quad n = \langle B^+, e^- \rangle, \quad A = \langle B^+, \mu^- \rangle.
\]

By adopting this model both the \textit{full symmetry} and \textit{Kiev symmetry} become self-evident, because it is the \(B\)-matter alone that is responsible for strong interactions, and it is just the lepton triplet that is the source of weak interactions. It should be stressed here that if we adopt the Nagoya model, it becomes unnecessary to introduce an artificial space, such as the isospace, into the theory. As I said repeatedly, it is a characteristic of our methodology to understand the mythological concepts in naturalistic terms.
As for the true nature of the \textit{B-matter}, we have nothing to say at present. Though we may imagine variant types of models for \textit{B-matter}, I do not think that it is so simple as to behave like a positively charged boson.* Perhaps it would be a substance belonging to the \textit{sub-quantum level} where the present theory is of no use. If our imagination is allowed its full play, the lepton triplet may be compared to three different persons who behave like quantum mechanical particles, and the \textit{B-matter} to some kind of alcohol like beer which makes them strong and massive if they drink it.

A further step toward the deeper structure of matter was taken by Taketani who proposed the \textit{neutrino unified model}. According to him, the electron and the muon are generated from the neutrino by loading an electric charge ($\varepsilon$-charge), and the mass difference between them comes from the variant types of loading, that is, the difference of the charge distribution. This idea was first proposed by himself and Katayama at S\~ao Paulo in 1958. But, after the proposal of the Nagoya model, he suggested to extend this idea to include the baryon by assuming that the \textit{B-matter} may behave as a charge-like substance ($B^+$-charge). Though the charge-like model for the \textit{B-matter} should be considered as a phenomenological and correspondence-theoretical approach to its true nature, it enables us to give a theoretical foundation to Matumoto's mass formula.¹⁰

The \textit{neutrino unified model} is stated as follows: The neutrino is the only urparticle of matter, from which all sorts of the basic and the fundamental particles are generated by loading $\varepsilon$-charge or/and $B^+$-charge on it. Just like the hyperons and the mesons are composed of the baryon and the anti-baryon, the photon may also be composed of the electron and the positron.

Though our view of matter seems to be nearly completed with the neutrino unified model, we should never forget the fact that the nature as a whole has a structure of inexhaustible depth. As the next step toward the deeper level of matter, we should have to disclose the true nature of both the \textit{B-matter} and $\varepsilon$-charge which belong to the sub-quantum level. And, even behind the neutrino, we should have to seek for the \textit{causa formalis} of its mode of existence.

\textbf{References}

1) N. Bohr, Faraday Lecture, 1930.
2) W. Heisenberg, Rev. Mod. Phys. 29 (1957), 269
4) M. Gell-Mann, Phys. Rev. 92 (1953), 833.

* This point has often been misunderstood by many authors, e.g. R. E. Marshak and S. Okubo, Nuovo Cimento XIV (1961), 1226.
19) K. Matumoto and M. Nakagawa, Prog. Theor. Phys. 23 (1960), 1181.