Theory of Elementary Particles and Philosophy*)

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Natural scientists may adopt whatever attitude they please, they are still under the domination of philosophy. —F. Engels, *Dialektik der Natur*

1. Yukawa theory and philosophy

It is about thirty years since Dr. Hideki Yukawa proposed his meson theory. At present, the π-meson is counted as one of the most familiar elementary particles and the Yukawa theory of meson occupies a central position in the theory of elementary particles. But, one has to admit that thirty years ago there was no atmosphere among physicists in the world to accept straightforwards a proposal of the meson theory. While looking back at the situation in those days, one immediately notices that the discovery of the meson theory was being awaited by the discovery of a neutron and the succeeding development of the theory of nuclear structure by Iwanenko and Heisenberg as the most natural course of the progress. However, the positivistic philosophies which were dominating over the scientific societies at that time were absolutely incompatible with the strong-minded methodology which underlies the Yukawa theory—introduction of a new kind of elementary particles. The strong and overwhelming influence of the positivistic philosophies was faithfully expressed by the fact that the neutrino hypothesis was proposed by Pauli a few years before the birth of the Yukawa theory but it never appeared as a paper in a scientific journal. After the Second World War, the existence of a π-meson was experimentally confirmed and a large accelerator succeeded in artificial production of a π-meson. As a result, all physicists in the world had to accept the Yukawa theory and the two-meson and two-neutrino theory which was proposed by the author as an extension of the Yukawa theory. In spite of those achievements, the governing philosophy over the scientific communities has been remaining unchanged. Mist of the positivism has been thick around all fields of the science since the beginning of this century. It is a famous story that there were repeated fruitless discussions of skepticism on the objectivity of the atom among the physicists including Ostwald and Mach even at the last night before days of disclosing the internal structure of the atom. The moment of proposal of the Yukawa's theory was in the middle

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of a revolutionary development of nuclear physics, whereas the positivistic philosophy of the Copenhagen school headed by Bohr was not able to have a correct perspective of this revolution. After that period, a frontier of physics went into problems of elementary particles from those of atomic nuclei. At present, it goes still further, entering into problems of the internal structure of elementary particles themselves. If one forgets the lessons of history and cannot make oneself free from a prison of the positivism, one will be bound to repeat a fatal mistake of the same kind again and again.

Just after the proposal of the Yukawa theory, Mituo Taketani developed his philosophy of the "three-stage" in development of the cognition and made clear a methodological significance of the Yukawa theory (M. Taketani, *Problems of the Dialectic Logic*, 1948. It is a collection of his philosophical works published since 1936 (in Japanese). A new reprint was published by Keiso-Schobo in 1968). This philosophy made it possible to extinguish the mist of positivism for us in Japan and to establish a penetrating perspective on a direction of development of sciences. Any emphasis will not be too much for the fact that the Japanese tradition of the theory of elementary particles was being established with Taketani's philosophy as its backbone.

2. Dialectic-philosophical view of nature and Taketani's philosophy

One may quote the following two points as remarkable features of the physics of the present century. The first is recognition of the strata-structure of nature, in particular a series of discoveries of new strata of the microscopic world, namely, molecules—atoms—atomic nuclei-elementary particles. The second is recognition of a limit of validity of the physical laws, in particular a discovery that the Newton mechanics is not the eternal truth of perfection. As a result, it established the following point of view for nature: there exist in nature an infinite number of the strata with different qualities with each other including the nebulae and the solar system as examples of a large scale and the molecules, the atoms and the elementary particles as examples of a small scale, each of those strata is governed by its respective and proper laws of physics, and all of the strata are always in the middle of creation and annihilation and they compose nature as the one and whole unified existence through their correlation and mutual dependence among themselves. This point of view is known as the dialectic-philosophical view of nature, and it was already put forward by Engels at the end of the nineteenth century. One may say as a conclusion that the atomic physics of the twentieth century rediscovered the dialectic-philosophical view of nature.

As soon as the scientific research penetrates into a new and unknown stratum of nature, physical concepts and laws established in the old strata quite often lose their validity. Under such circumstances, one has to rely mostly on the experimental facts. Thus, it is natural that the first step into the new stratum will begin from a stage of the phenomenology, that is, a stage of research describing the new phenomena as they are. If a physicist loses himself with a surprise of seeing novelty in the new phenomena and neglects completely reliability of the concepts which belong to the old strata, then he will often fall into the skepticism against even reality of the objective existence itself and he will be captured by philosophies of the positivism or the empiricism believing that only the experience is his basis. On the other hand, if he sticks to concepts and laws of the old strata and pays no attention to any of new ideas which are compelled by the new experiments, then he will be bound to a metaphysical point of view of obstinacy. One finds many examples of both the inverted tendencies in the history of science at the beginning of this century. For example, a large number of people believed the energetics of Ostwald and the economy of thought by Mach, as was critisized by Lenin in his *Materialism and Empirio-Criticism*. Then, there were severe controversies between these people and those with a point of view of the old atomistics, including Boltzmann and Planck. At the moment of the birth of the quantum mechanics, there was a conflict of opinions between the school of the matrix mechanics and the school of the wave mechanics, where the former had an inclination towards the positivism while the latter towards the realism. There were continued discussions of such type between Bohr and Einstein over a long period, even after establishment of the quantum mechanics.

After the stage of phenomenology one has a stage of discovering the substance of the new stratum which underlies the new phenomena, and then the next stage of disclosing new rules which govern the new stratum. Mituo Taketani named the former the substantialistic stage and the latter the essentialistic stage. His theory claims that the cognition of nature is a dialectic-philosophical process which advances in a spiral form and a cycle in the spiral is composed of the three-stage—phenomenological, substantialistic, and essentialistic stages. His theory has its basis on the dialectics of nature, namely, the strata-structure of nature itself. If one takes an example from the quantum physics, discoveries of regularities in the atomic spectra are regarded as belonging to the phenomenological stage. Establishment of the atomic model of Rutherford and development of the early quantum theory of Bohr correspond to the substantialistic stage. Then came completion of the quantum mechanics which is the essentialistic stage. It should be pointed out here that one always finds in the essentialistic theory new buds of the phenomenological character which prepare for future development into deeper strata of nature. As was rightly pointed out by Bohr in 1930, there are quantities in the theory which are never derived from the whole system of the quantum mechanics, but are given only from outside of the system as accidental elements. He showed the example such as ratio of mass of a proton and of an electron or the fine-structure constant which determines strength of the electromagnetic interaction. We will see in the next paragraph that those accidental elements attract more and more attention of scientists and become a point of breakthrough for the next development of physics.

After establishment of the quantum mechanics, idea of the complementarity was proposed by Bohr as its philosophical basis. The Copenhagen interpretation of the quantum mechanics has this idea as its backbone. The philosophy of complementarity was successful in giving a dialectic-philosophical view on the quantum mechanics as such that it is an essential rule lying beneath the quantum phenomena of mutual contradiction between the wave-character and the particle-character. But it did not make clear a dialectic-philosophical relation between the logics in the substantialistic stage and that in the essentialistic stage, so that it became a cause of spread of the positivistic tendency in the Copenhagen school. And this tendency was further accelerated by giving fixed ideas without any criticism to the two theses of Neumann, which were proved by himself with mathematical accuracy (S. Sakata, "On Interpretation of the Quantum Mechanics," *Kagaku*, 1959 (in Japanese), and M. Taketani, "Problems on Interpretation of the Quantum Mechanics," *Kagaku*, 1964 (in Japanese)). A particularity of the Copenhagen interpretation is to regard the Schrödinger equation as the rule given beforehand, and to concentrate their attention to the interpretation with the logic of complementarity on the problem how the phenomena are mediated with the Schrödinger equation. But, when one is going to apply the quantum mechanics to some concrete object, one must start from constructing the Schrödinger equation itself. For this practice one necessitates the substantialistic knowledges such as which kinds of material are composing the object and which type of forces is acting between the components. This point was clearly understood in the correspondence principle of Bohr in the early days, but the later development made the Copenhagen school, including Bohr himself, neglect important role of the substance more and more. The reason is that the Copenhagen interpretation is on the standpoint of "appreciation". Contrary to it, Taketani's philosophy is on the standpoint of "practice". So, by this reason, Taketani pointed out that the substantialistic knowledge is an indispensable element of the whole system of the theory, and he emphasized an important role of the substantialistic stage in the cognition of nature. It was indeed an excellent work of Taketani that he made a penetrating analysis on the contemporary physics with his philosophy of the "three-stage" and defined the situation as in a stage where the physics was putting order in itself with the substantialistic terms and it was looking for a way of advancement into the essentialistic studies. By this reasoning, he put great emphasis on methodological significance of the Yukawa theory. It was Taketani's philosophy which gave encouragement and provided a philosophical basis for us to advance into an introduction of the neutral meson and a proposal of the two-meson and two-neutrino theory.

3. Dialectic-philosophical viewpoint on elementary particles and method of composite model

Kinds of elementary particles have increased in a remarkable way in these ten or twenty years. After the discovery by G. Rochester and C. Butler of *V*-particles in 1947, the experiment made clear the existence of a group of elementary particles called then the "new particles". More recently, the experiment with a large accelerator has been providing us information on existence of varieties of particles of very short life-time, called the "resonance particles". How can one understand the existence of such varieties of elementary particles? From the dialectic-philosophical point of view of nature, the elementary particles should not be considered as the ultimate element of matter like the atoms in the ancient Greek natural philosophy, but they must be regarded as one of the strata of infinite number in nature in the same way as for molecules, atoms and atomic nuclei. Various regularities found in properties of elementary particles—the mass spectrum, structure of their interaction, the symmetry property, and so on—should not be considered as a "forma" given by the "Providence of God", but one should look for "causa formalis" in the stratum lying deep beneath that of the elementary particles.

From this point of view, the author proposed in 1955 the composite model of elementary particles—a hypothesis claiming that all of the strongly interacting elementary particles are composed of particles and antiparticles of three kinds of the fundamental particles, namely, proton, neutron and Λ-particle (S. Sakata, "New Dialogue on the Elementary Particles", *Butsuri* 1961 (in Japanese),*) also see *Prog. Theor. Phys.* **16** (1956), 686). An intention of the model was to pick up the Nakano–Nishijima–Gell-Mann rule on reactions of the strongly interacting elementary particles and to provide a basis for the rule. The idea that the existence of three kinds of "fundamental particles" is a "causa formalis" of the above rule can be compared with the old idea of "atom" introduced as a basis for the regularities found in chemical reactions, such as the "law of definite proportion" and the "law of multiple proportions". A characteristic of the composite model is to give the "logic of matter" of the deeper stratum to the Nakano–Nishijima–Gell-Mann rule which was proposed as a "logic of form" of the stratum of elementary particles. A choice of a proton, a neutron and a Λ-particle as

*) Editors' note: See the article pp. 185~198.

the three fundamental particles is a matter of accident, and essence of the model lies in its methodology of discovering the "logic of matter" through the "logic of form". If one may cite a few lines from an ancient Chinese philosopher, Zhuangzi, whom Yukawa likes very much, this can be expressed as follows: "Logos inherent in all things is attained on the basis of beauty in Heaven and Earth" (translation by H. Yukawa).

As far as one sticks to a viewpoint of regarding elementary particles as the ultimate element of matter, the quantum theory of field-theoretical approach will be a unique way of study on elementary particles. But, from a point of view of the composite model, elementary particles are regarded as a system of many-body like an atomic nucleus so that one will have a variety of approaches to study the elementary particles as in a case of nuclear physics. Furthermore, the model is able to find a variety of the theoretical approaches—the group-theoretical method, the method of S-matrix, the theory of non-local field, the nonlinear field theories and so on—not in a mutually contradicting way but in their mutual correlation, one being complementary to another. This is another property of the composite model.

The group-theoretical approach is one of various ways which started from the composite model and it is gaining the most successful results up to the present time, showing its effectiveness in classification of the known elementary particles and prediction of new kinds of particles. In 1959, Ogawa and Klein, independently, pointed out that there exists equality over the three fundamental particles in their role on the strong interaction, and there is a relation of the full symmetry between those three in a good approximation. This was the first step of the group-theoretical approach for elementary particles. Then, Ikeda, Ohnuki and Ogawa found that a group of the full symmetry is a three-dimensional unitary group U_3, and they tried to make classification of elementary particles following their irreducible representation (1959). For example, they related the three fundamental particles to the three-dimensional representation and π-mesons and K-mesons to the eight-dimensional representation, considering them as a two-body system of a fundamental particle and its anti-particle. As a result, they predicted the existence of a new type of meson of its isospin 0 and of the same spatial property (parity) as π- and K-mesons. A meson of such type was found later by the experiment and was named η-meson.

Later development of the group-theoretical approach and accumulation of the experimental data on the resonance particles proved validity of the composite model and, at the same time, necessitated its modification in some respect. In particular, Gell-Mann (1962) and Ne'eman (1961) pointed out that classification of the baryons could be better performed if a proton, a neutron and a Λ-particle are regarded as members of the eight-dimensional representation together with Σ-particles and Ξ-particles. If the proposed correspondence will be proved to be correct, the fundamental particles in the composite model will not be a real proton, a neutron and a Λ-particle, but one will have to look for existence of the "urbaryonic particles" with similar physical properties as those of the three in the original assumption. At present, there are varieties of possibilities on what the fundamental particles are, and one has not yet reached any final conclusion. One may refer to the quarks proposed by Gell-Mann (1964) as one of the simplest and least modification of the original model. The quarks have a strange property of the fractional charge, but one may be not too serious on this point because they belong to the stratum of the super-quantum mechanics. Rather, one should be more careful against the pest of the group-theoretical approach and the positivistic tendencies where one fixes a "logic of form", such as the symmetry property, as the ultimate principle in physics and regards introduction of the "substances" such as the quarks as only a conventional way to discover the "logic of form".

In 1959, we advanced a step forward with "method of the composite model" and made a proposal of the "Nagoya model", which offers a unification of the baryons and the leptons. And then, Taketani and Katayama proposed the "neutrino unified model" (1960). In the Nagoya model, one assumes that each of the three fundamental particles is made of one of the three leptons—a neutrino, an electron and a μ-meson—with the "B-matter", which is material of the super-quantum mechanical stratum. While in the neutrino unified model, one assumes that the neutrino is the fundamental in the three leptons and the other two are formed by a neutrino with attachment of the ε-charge. Characteristics of the Nagoya model lies in transforming the "logic of form" of the "fullsymmetry" into the "logic of matter" of the "B-matter" and at the same time attributing symmetry properties between the baryons and the leptons as seen in their weak interaction to the "logic of matter" of having a lepton in the inner-structure of the fundamental particles. One sees here a faithful application of the method of a composite model with which one advances to the logic of matter from the logic of form. In the neutrino unified model, homogeneity and heterogeneity of the three types of leptons are attributed to different ways of the attachment of the ε-charge to a neutrino. Here again, the model is based on the same philosophical methodology. Later experimental discovery of the two types of neutrino made such modification to the model, that the B-matter attaches only to a particular superposing state of the two neutrinos (1962). The modified Nagoya model is better than the original one in giving a natural interpretation for the so-called "Cabibbo-angle".

The most important problems lie in a question what the fundamental particles of the composite model are. But, observing from a viewpoint of the Nagoya model, one notices that a variety of the models so far presented have no essential difference among them, and all of their difference can be reduced to different properties of the assumed *B*-matter. For example, the quark model corresponds to the *B*-matter of charge 2/3, and of baryonic number 1/3, and "the quartet model" of Maki and Ohnuki (1964) and "the double triplet model" of Van Hove (1964) to the introduction of the neutral *B*-matter besides the ordinary charged *B*-matter. Even if the fundamental particles are not directly observable, the nonobservability can be attributed to a special property of the *B*-matter, as was discussed by Taketani and Katayama in their "neutrino core model" (1965).

Another important point of the Nagoya model is that this model inherits all successes of the original composite model on problems of the weak interactions—for example, conservation of the vector current. This emphasizes importance of the position of the Nagoya model.

There is one more important problem concerning the composite model. It is a question that the meson family may belong to a different stratum from that of the baryon family. The original composite model was successful on problems of the meson family and never encountered such difficulties as happened in the case of the baryon family. We saw already the various modifications proposed in connection with the difficulty, but all of them are almost the same as the original one for the meson family. But here remains, as a matter of principle, the following question: whether the meson family is a direct composite of the fundamental particles, or the baryon family is the direct composite and the meson family is made of a particle and an anti-particle of the baryon in an analogous way of a molecule being made of atoms. Those who are not conscious of the dialectic-philosophical point of view may consider only the former possibility, but an answer to this question is most important for the future progress of the elementary particle theory. It is the fact that the experiment could not yet be successful in finding a possible existence of the fundamental particles, and it seems more favourable to the latter possibility. It is hoped that the future progress of physics of high energy and extremely high energy will clarify the question.

Above all, I believe that the model of the elementary particle will change its concrete form step by step with progress of the experiment. If one sticks to a particular form and does not accept any alternative, this is a metaphysical point of view and it has nothing to do with the dialectic-philosophical viewpoint. The method of "composite model"—transformation of the logic of form into the logic of matter—will advance forever confronting the positivistic philosophies. Here, a current abstract method of the group-theoretical approach will be useful only in preventing fixation of a certain concrete model, gained at a certain stage of the experimental progress. Once one forgets this remark and will fall into a way of abstraction without any precaution, one will spread an inverted viewpoint of believing the ultimate aim to be a discovery of the symmetry properties, as the "Providence of God", and then the physics will fall down into one of the theologies. The same criticism should be applied, too, to the method of S-matrix which intends to avoid the inner structure of the elementary particles and approaches the problem far outside of the elementary particle. Sometime ago, I critisized the contemporary theory of elementary particles quoting the three evils, "oblivion of the history", "empiricism" and "fixation". Here again, I quote the same three as the final remark.