The Legacies of Yukawa and Tomonaga*)

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For this symposium to commemorate the accomplishments of Tomonaga and Yukawa, I will talk about their lives and their place in the history of physics. Then I will go on to some reasonable spot and speculations or my view of what physics is doing at this moment. I discuss my view of physics or kinds of attitudes that I had in doing physics, as well as looking forward to the future of physics and some of its speculations.

§1. Introduction

This is an international meeting to honor and commemorate the scientific achievements of Yukawa and Tomonaga. The venue, however, is Kyoto, and there are international as well as domestic participants. I would like therefore to reflect on both the scientific and the cultural aspects of the lives and the accomplishments of the two physicists and others who were closely associated with them. Many of the people who gathered here may have also participated in conferences of various kinds that preceded this meeting. At any rate, I suppose most of them are fairly familiar with what may be called the Yukawa-Tomonaga phenomenon, but I would like to present it in my own way.

Historically, Japan was initiated into advanced civilization roughly fifteen centuries ago through the influences of China and India. She learned astronomy and mathematics from them, but in time she started to make her own developments. The Renaissance and the global expansion of the Western world more or less coincided with the establishment of a stable feudal regime that controlled the entire country but closed to the outside world, and lasting until the mid-19th century. I think this period of some 250 years was responsible for molding most of what we may regard as the typical Japanese characteristics. Although the country was a closed one, the Western science and mathematics seeped slowly through the barriers in a measured way. When Japan joined the global community 138 years ago, they were ready to participate fully in the pursuit of modern science.

H. Nagaoka (1865–1950) and Y. Nishina (1890–1951) are two of the notable physicists who played a large role in the development of science and science policy in Japan. Both had studied in Europe. Nagaoka, although he proposed a Saturnian model of atoms soon after the turn of the twentieth century, in his later years took a rather conservative attitude toward the subsequent revolutions in physics. Nishina, on the other hand, brought back his experience both with Rutherford and with Bohr. In 1931 he joined the laboratories of RIKEN in Tokyo, which was a brand-

*) This is the manuscript prepared for his lecture scheduled at the Yukawa-Tomonaga Centennial Symposium. The lecture was, however, not given in the Symposium since he caught a cold, and was instead presented two weeks later on Dec. 26 at Yukawa Institute for Theoretical Physics.
new concept in research organization, originally spurred by the needs of the country when the outbreak of World War I stopped the influx of information and technology.

Nishina is the father of big science in Japan. He started a group of cosmic ray research and a group to build cyclotrons for nuclear physics, with a kind help from Lawrence. These were then emerging new fields of physics. He also brought the “Copenhagen spirit” of free discussion to the physics community, as is often mentioned in connection with Yukawa and Tomonaga. In their student days they are said to have been deeply impressed and motivated when Nishina visited Kyoto and gave lectures. Tomonaga ended up joining Nishina’s group at RIKEN as a house theorist, while Yukawa was arranged to join a newly created university in the city of Osaka, known for its businesslike pragmatism and vitality.

§2. Hideki Yukawa and Shin-itiro Tomonaga

Now about Yukawa and Tomonaga. It looks like a striking coincidence that each was born around the same time into a family of scholars with old samurai lineage. Both spent their infant days in Tokyo, but settled in Kyoto when their fathers got an appointment at Kyoto University. The ancient capital being rather compact and resistant to change, they attended the same grade school, and were able to commute on foot all the way until their university days. Kyoto had an accumulation of prestige, culture, and dignity. Being free from the pressures of national politics, it also nurtured the spirit of free and original thought, as is exemplified by the Nishida school of philosophy and a school of liberalism.

There are also differences and contrasts between Yukawa and Tomonaga, which make for a favorite subject of discussion. Yukawa was deeply influenced by Oriental philosophy and literature inculcated by a strict grandfather. He indulged in Chinese calligraphy and Japanese Tanka poetry. Tomonaga, although he too practiced those, was of more modern inclination, his father being a philosopher of the Western kind, and was sensitive to Nature and susceptible to human foibles. Yukawa was argumentative. He was a good polemicist, willing to be a lone wolf. Tomonaga was meticulous. He was a good story-teller, a consensus builder. But physics needs both types.
Table I. Biographical sketches.

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<td>Born in Tokyo, then moves to Kyoto</td>
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<td>Father, adopted into Ogawa family, professor of geology at Kyoto University</td>
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<td>Hideki's brothers also became scholars</td>
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<td>1926 Enters Kyoto University</td>
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<td>1929 Unpaid lecturer</td>
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<td>1932 Adopted into Yukawa family</td>
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<td>1933 Lecturer, Osaka University</td>
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<td>1934 Meson theory hypothesis</td>
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<td>1937 Discovery of cosmic ray muon by Anderson and Neddermeyer followed by Nishina's group</td>
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<td>1939 Professor, Kyoto University</td>
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<td>1947 Discovery of pion by Powel's group. Proposes nonlocal theory</td>
<td>1947 Discovery of the Lamb shift</td>
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<td>1948 Member, IAS, Princeton</td>
<td>1948 Renormalization theory</td>
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<td>1949 Nobel Prize</td>
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<td>1952 Director, the Yukawa Institute</td>
<td>1950 Theory of 1-dimensional media</td>
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<td>1955 Joins the Russel-Einstein declaration</td>
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They both represented the ideal Oriental scholar, who is supposed to be a cultured person in the first place. No doubt they were good and worthy rivals on all counts. Over the span of their lives, they were equally productive in writing essays and monographs, and engaging in dialogues with people of all trades. The collected works of each, besides scientific papers, make up a dozen or so volumes, which I can find in the University of Chicago Library. But their styles are clearly different.

It is also remarkable that each of them happened to nurture a very able group of physicists, who just seemed to sprout around him in a timely manner. This seems especially true of Yukawa, but these people actually moved easily from one leader to the other during their careers. S. Sakata (1911–1970) is the most notable example, who made his own unique achievements which rival those of Yukawa and Tomonaga. When I was a student at the University of Tokyo, some of us went to seminars at nearby RIKEN conducted jointly by Nishina and Tomonaga, and on one occasion Tomonaga read before us a letter from Sakata, his former colleague, regarding his two-meson hypothesis which predicted the \( \pi - \mu \) decay chain of cosmic ray “mesons”.
§3. Yukawa and Tomonaga in twentieth century physics

This now brings me to the main theme of the talk, namely the places they hold in the history of particle physics.

The twentieth century was a truly revolutionary time for physics. Quantum mechanics and general relativity have extended our view of the natural world from the very small to the very large, spanning 60 orders of magnitude. By the late 1920s, the basics of the revolution have been laid down, but there still remained unexplored and unsolved problems. One of them was the substantive question of the makeup of atomic nuclei, the nature of the strong force and the weak one. Another was the inherent difficulties in the mathematical structure of quantum field theory.

Looking back to 75 years ago, it may strike us rather strange that the basic constituents of matter, i.e., the so-called elementary particles, were thought to be only the electron and the proton. They took it for granted that the truly elementary particles that make up our world should be as few in number as possible, ideally only one. When we were forced to admit that there was the neutron, too, Dirac, for example, rationalized it by saying that if there are already two kinds, perhaps it is all right that there are three.

What we now call particle physics, or high energy physics, was born in the 1930s when people began to change that view of the physical world. I once called E. Lawrence and H. Yukawa the founding fathers of particle physics, one experimental and the other theoretical. Lawrence invented the cyclotron, and ushered in the era of ever larger accelerators, their energy increasing so far by a factor of ten every decade. Yukawa, on the other hand, started the theoretical attitude of expecting, or postulating when necessary, the existence of new particles with ever increasing mass. The theoretical expectation and the accelerator technology helped each other leading to enormous successes up to the present time. Thus, Lawrence and Yukawa had set the overall trend of particle physics which continues to this day.

Tomonaga’s role, on the other hand, is of a rather different nature. The present framework of particle physics represented by the Standard Model stands on a few basic principles:
1. Quantum field theory with renormalization
2. Gauge principle
3. Spontaneous symmetry breaking

Relativistic quantum field theory is a most logical extension of the quantum mechanics started by Heisenberg, Schrödinger, Dirac and Pauli. But from the outset it had the problem of infinities, or the divergence of the effective parameters in the theory, like the masses and the interaction constants. This difficulty was already inherent in classical field theory due to the pointlike nature of particles in interaction. If we were to follow Yukawa’s paradigm, we would postulate a set of known and unknown particles, and let their divergences cancel each other, as A. Pais and S. Sakata tried. It did not work. Another rather natural solution might be to abandon the pointlike nature of elementary particles, as indeed Yukawa himself and others advocated, but without success.

Tomonaga’s solution, also independently developed by Feynman and Schwinger, was to show that one can consistently isolate the infinities and deal with the physically relevant quantities without ambiguities. This concept of renormalization originally looked like a half-hearted compromise, but its universal relevance and effectiveness have been fully demonstrated by its successes, and its true meaning has also been elucidated by K. Wilson later. The Pais-Sakata solution as well as Yukawa’s proposal, however, may not have been completely off the mark after all. In a sense supersymmetry may be thought of as its modern incarnation, although its motivation is entirely different. Yukawa’s proposal, too, finds its more sophisticated avatar in superstring theory. Still, the concept of renormalization remains to be an essential ingredient of quantum field theory.

§4. Three modes in physicists’ research and the present physics

Now I do not want to venture into speculations on the future of particle physics in the 21st century. But I would like to make some general observations. Once I classified theoretical physicists into three types according to their different styles of approach, and called them Heisenberg (H), Einstein (E), and Dirac (D) modes,
ring to their most characteristic contributions respectively, i.e., quantum mechanics, theory of gravitation and the Dirac equation. Heisenberg’s is heuristic, bottom-up, and inductive. Einstein’s is axiomatic, top-down, and deductive. Dirac’s is abstract, revelational, and esthetic. Of course theorists do operate in different modes at different times, with different degrees of success, so labels should actually be attached to individual works rather than the individuals. It would be safe to say that Yukawa belonged to H when he proposed the meson. He failed in E when he tried his hand at nonlocal theory. I have a bit of difficulty applying this to Tomonaga, but I will assign him to E. Most theorists belong to H or E. But, when it comes to contrasting Yukawa and Tomonaga, it may be appropriate to use the analogy to designer vs craftsman.

I am going to depart from an analysis of Yukawa and Tomonaga themselves. Where do we stand after over seventy years of particle physics? I claim that the dominant mode of particle theorists for the last thirty years has been shifting gradually from H to E to D. Think of the shift from meson to renormalization to gauge theory to superstring. The standard model brought H and E to a successful conclusion. Now we seem to be into D. Dirac once commented in connection with his theory of monopoles that it is so beautiful that it had better be adopted by Nature. Beauty here is of course an abstract mathematical one. Many people seem to have been attracted by supersymmetry and superstring theory primarily because of their inherent beauty and elegance. The underlying reason for this trend seems to be that the theorists have been too successful in the past. Theory can freely make speculative jumps whereas experiment is bound by the technical and social realities. The former can leapfrog but the latter cannot.

Be that as it may, I have always wondered about the solubility, or comprehensibility of Nature. Why is it that we are successful in getting deeper and deeper into the laws of Nature? Why is it that year after year we submit research proposals with ambitious plans, and we report satisfactory results most of the time? Why is it that bigger experimental facilities so far have not failed to make more discoveries? Finally, why is it that some 13.7 billion years after the beginning of the universe we are discovering that truth, and are going to predict its future as well, including the possible demise of itself? (Think of an analogy to human development. Are we entering puberty now?)

One may say that these are metaphysical questions rather than physics. But I think the distinction between them is getting more obscure these days, especially with the activities of string theorists. I regard this fact itself a progress of sorts, or at least an enlargement of our vista. We may be entering a stage of physics where it is possible or meaningful to ask such questions in an objective and concrete manner. One can discuss the possible universes and their histories, including our own, in precise mathematical terms. Eventually we might be able to get an answer, positive or negative, to the comprehensibility of Nature.

§5. Comprehensibility of nature

Concerning this last point I would like to make the following simple observations.
5.1. **Power of analogy**

When we discovered the electron, and began to explore the atomic structure of matter over a hundred years ago, we already had a model in the solar system. Such a model did help. If phenomena of completely different scales had nothing in common, we would have great difficulty exploring them, even if in the end we might be able to find the answer by sheer observation of the facts. But we can explore the unknown world only with the equipment we already have. After all we are animals which can move around. A stationary plant grown inside an artificial satellite would not have the notion of force. Could it have discovered the Newtonian dynamics?

5.2. **The Hamiltonian structure of physical laws**

Both a single atom and a macroscopic object made up of a great number of atoms can be described by the same type of Hamiltonian. Only the parameters are different. The fundamental reason for this is because one can isolate the center-of-mass coordinates from among those of all constituents which are irrelevant within a certain range of phenomena. Mathematically it is due to the inherent structure of Hamiltonian dynamics. Without it, how could we have been able to reduce the diverse physical processes to a few basic laws? By the way, what we call renormalization is a particular manifestation of the same general property.

5.3. **“Unreasonable effectiveness of mathematics”**

I once listened to a seminar by E. Wigner in which he mused over the “unreasonable effectiveness of mathematics” in describing the physical world. Unreasonable or not, it is a fact, and it seems to be getting more and more so. One may call this dictum of Wigner’s the fundamental axiom of physics. Physics would not be possible without it. The Standard Model would not have been possible without following the mathematical logic we had created. And it helps enhance the comprehensibility of Nature by enabling the physicist to develop mathematical intuition in addition to the physical one. But is the axiom ultimately true? I do not know, but hope so.

5.4. **“Physics is like a maze”**

Again quoting Wigner, he has also made an observation which I will paraphrase as follows. Physics is like a maze. First you have to make the right choice of path to begin with. Then you can proceed to the next point, and you have to make the right choice there again, and so on. Soon it will get easier, and things will keep going smoothly leading to the final goal. But if your first guesses are not right, you will be frustrated getting nowhere. To this I would like to add a comment: In physics, wrong first choices, if they are natural and intelligent ones, may nevertheless lead to something unexpected and eventually valuable, as it once did happen to Columbus. Physics is fun, after all.

§6. **Epilogue**

I end with a couple of anecdotes I have learned. Yukawa once joined a picnic organized by the physicists of his Institute to climb Mt. Hiei, which hugs the city of
Kyoto on its northeastern side, and is famous for a complex of Buddhist temples up there. As they walked up, they came to a lookout point with a splendid view of the city. So they proposed to rest a while and enjoy the scenery. But Professor Yukawa was not interested. He just kept walking straight up doggedly toward his original goal.

Tomonaga in his later years served as president of his university. This was engineered by some academic people around him, but it was a delicate task. As the deadline for his answer was nearing, two of those involved in the plot made a visit to his house, carrying a bottle of whisky. Tomonaga received them and spent the whole evening chatting and drinking. Toward daybreak the bottle became empty. As they were going to leave, they finally asked him casually, “You accept the presidency, don’t you?” He just nodded. Mission accomplished.

Acknowledgements

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