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Nambu, A Foreteller of Modern Physics II

Yoichiro Nambu: remembering an unusual physicist, a mentor, and a friend†

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I was lucky to meet Yoichiro Nambu at the beginning of my scientific activity. The experience of working with him influenced my subsequent research and in the following I will try to convey what he transmitted to me. It was also a friendship that continued for decades in spite of the rare occasions to meet after our collaboration.

Subject Index B02, B31, B36, B37, B60

1. Chicago, spontaneous symmetry breaking, analogies

I arrived in Chicago in September 1959 as a research associate in the theory group of the Fermi Institute. I had an invitation from Herbert Anderson, at that time director of the Institute, who had spent one year in Rome, where he had given a course on elementary particle physics. I had written, together with Ugo Amaldi, the notes for this course and this is how I met him. In the summer of 1959 Nambu, on his way to the Kiev Conference, had given a seminar in Rome on his work on Green's functions in quantum field theory. I attended the seminar and in my answer to Anderson I expressed the wish to work with Nambu.

Heisenberg was probably the first to consider spontaneous symmetry breaking (SSB) as a possibly relevant concept in particle physics [1], but he chose the wrong symmetry to be spontaneously broken. It was the intuition of Nambu that allowed him to grasp the analogy between chiral symmetry and gauge invariance in the theory of superconductivity of Bardeen, Cooper, and Schrieffer (BCS).

The prehistory of this turning point has been recounted by Nambu in the introduction to his collected papers [2]. He says:

I was very much disturbed by the fact that their (BCS) wave function did not conserve electron number. It did not make sense, I thought, to discuss electromagnetic properties of superconductors with such an approximation. At the same time I was impressed by their boldness, and tried to understand the problem. I ended up becoming captive of BCS theory.

Nambu's paper on superconductivity [3] was a key step as it reformulated BCS theory in a field theoretic language in which the analysis of gauge invariance became particularly transparent and the analogy with chiral invariance could be formulated clearly. Furthermore, simply on the basis

†The source of this article is chapter 7 of the memorial volume for Professor Yoichiro Nambu published by World Scientific.

of invariance arguments, Nambu realized that zero-mass particles, later called Nambu–Goldstone bosons, were associated with SSB [4].

Nambu and I have reported on previous occasions how our model, now known with the acronym NJL, developed. I will not repeat the story here but refer, e.g., to Ref. [2], Ref. [5] and also Ref. [6], where I elaborate on cross-fertilization and analogies in theoretical physics.

To understand the impact of working with Yoichiro, I must emphasize that my education in physics in Rome had been phenomenologically oriented while my inclinations pushed me towards a more formalized theoretical approach. The types of questions that interested me were of a more foundational character and sometimes I had the feeling that phenomenology was not my natural habitat in spite of the excellent instruction that I had received. Yoichiro somehow legitimized my inclinations. I learned from him two important principles: never be afraid of thinking unconventionally; and analogies are a powerful source of ideas.

We worked together intensely for fifteen months but at the end of 1960 I came back to Italy mainly because of family reasons, in spite of an offer to remain at the Fermi Institute. The director said to me, "For your work it would be much better to stay here." I believe that Yoichiro was behind the proposal; we understood each other very quickly and I had developed a kind of elective affinity for his way of thinking. To interrupt the collaboration with Yoichiro was very frustrating and made me very unhappy. Looking retrospectively, however, this pushed me to acquire a greater independence in my research, starting from the new horizons that had opened up in Chicago.

Back home, I tried to make good use of what I had learned. In this connection I mention three works in which analogies were the leading thread. With two of my former students, we made an analysis of gauge invariance in systems of nonrelativistic bosons like superfluid helium, also a case of SSB, inspired by Yoichiro's article on superconductivity, obtaining interesting new sum rules [7]. Then I tried to exploit in a series of papers the formal similarity in structure of quantum field theory and statistical mechanics. In the first of these papers, I introduced the so-called effective action, the generating functional of the one-particle irreducible amplitudes, which became popular and a standard tool in the study of spontaneous symmetry breaking [8]. In a work in collaboration with Carlo Di Castro, we imported the field theoretic renormalization group into the study of critical phenomena [9], a work especially appreciated by Russian physicists. This was two years before the celebrated papers of Ken Wilson. In those years, the 1960s, Yoichiro was permanently in my mind and the question was always what he would think of my work.

2. A long intermission

For several decades after Chicago, Yoichiro and I met very seldom but we continued to correspond. Due to my progressive shift towards statistical mechanics we did not attend the same conferences and our relationship was based essentially on a feeling of friendship rather than on scientific exchanges. He visited Rome in 1962 on vacation with his family and his son John told me recently that he still has vivid and pleasant memories of that trip. Then we met again in Italy in 1963 and in Chicago in 1967, which I visited on my way back from a summer at SLAC. At that time he was working on equations for wave functions with infinitely many components while I was still exploiting the analogies between quantum field theory and statistical mechanics.

The next important occasion was his 65th birthday in 1986. Peter Freund and Reinhard Oehme organized a meeting in honor of Yoichiro and asked for contributions for an issue of Progress of Theoretical Physics. I thought that I should contribute something connected with SSB. At that time I was interested in explaining the existence of chiral molecules, the so-called Hund paradox, and had

shown in collaboration with Pierre Claverie that an explanation, consistent with experimental data, could be SSB. In fact, we never observe isolated molecules, so collective effects are possible. The contribution that we submitted [10] showed that the argument could be extended to explain several other molecular phenomena that take place in a semiclassical limit once one takes into account the interaction of a quantum system with the environment. These ideas were later appreciated by Arthur Wightman [11] and the subject is one to which I return intermittently due to its general significance for quantum measurement theory too. It is the long time tail of my collaboration with Yoichiro.

On that occasion with Yoichiro and his wife we recalled the old Chicago days and he made a surprising statement: "At that time I was very insecure in my work." This is an interesting insight into the intellectual itinerary of Yoichiro.

I visited again Chicago ten years later in 1996 during a tour in the US. I remember talking with Oehme about the possibility of a Nobel Prize for Yoichiro and he explained that there was some opposition on the part of condensed-matter physicists, who considered SSB a common phenomenon in their field, so that it could not be considered a new discovery. Apparently, they were overlooking the fact that in particle physics it had been a major turning point and that only after the transfer into particle physics had the generality and key role of this concept been recognized.

I had hoped to see Yoichiro in Rome for my 70th birthday. He was expected to attend a meeting organized by my friends for the occasion but at the last moment he could not come. However he contributed an important paper [12] to an issue of the Journal of Statistical Physics dedicated to this event and sent a warm letter to be read publicly, for which I was very grateful.

3. The last years

The Nobel Prize, overdue in my opinion, was finally awarded to Yoichiro in 2008. Due to this event, our relationship again became very close and intense, as he asked me to represent him in Stockholm. The story went as follows. Obviously, I immediately sent him a message of congratulations but he did not respond for two weeks. Then he sent me the following short message:

It hurts me that your name appears only in the papers they quoted. I am not going to Stockholm because of my wife's health conditions and mine. But I hope to see more of you.

Some days later, he sent a new message with the proposal of replacing him for the Nobel lecture but emphasizing that I should be free to say no, and that he would understand. I greatly appreciated the messages and felt honored by the proposal; my admiration for Yoichiro was unconditional. Besides, it was an occasion for me to revisit my past in particle physics. Yoichiro said that he would send a text for the lecture but what he actually sent me was material that he had used in previous lectures and a beginning for the Nobel lecture devoted mainly to his biography. This material was very heterogeneous and not easy to use in a thirty minute lecture that should illustrate the impact of SSB in the evolution of particle physics. Luckily he said "use it your own way". So I prepared the slides in "my own way", proposed a title, and submitted them to him. The gratifying answer was, "You have done a better job than I!"

One year later we met in Kyoto for a meeting in his honor and we had a chance to talk at length. At this meeting I presented some less conventional examples of SSB, among which was SSB in statistical systems out of equilibrium. In particular I discussed a very simple toy model that showed that SSB could take place in nonequilibrium even if it was impossible in equilibrium. This model was known to statistical physicists as a model for a traffic jam but also, in a suitable interpretation, as

a case of spontaneous CP violation. I suggested that the different behavior of SSB out of equilibrium could be of interest in cosmology in connection with the matter–antimatter asymmetry problem. I sent to Yoichiro a paper that I wrote after the meeting [13] and here is his concise reaction:

The traffic jam problem is interesting. Recently I actually thought of the traffic problem while driving on Chicago Expressways.

At that time he was spending part of the year in Japan, where his wife was receiving medical care, but commuting to Chicago was very tiring for him. Later he decided to live permanently in Japan, near Osaka. His health was worsening, due to kidney problems that were hereditary in his family but had not bothered him previously, and he needed frequent dialysis.

Yoichiro Nambu was an unusual physicist. When he proposed an idea, a frequent natural reaction of the audience was "How did he think of that?" He had an associative mind with a remarkable mathematical taste and a special feeling for algebraic structures. An outstanding example is provided by the so-called Nambu mechanics formulated in 1973 in a paper with the title "Generalized Hamiltonian dynamics" [14]. In his last years, he came back to this subject, which was entirely his creation, with a recent follow-up both in mathematics and physics.

Let me give a few details, as this work is perhaps not so widely known as his other contributions. Suppose you have a triplet of canonical variables (x_1, x_2, x_3) that is one in addition to the usual (p, q) and equations of motion of the form

$$\dot{x}_i = \sum_{jk} \epsilon_{ijk} \frac{\partial H_1}{\partial x_j} \frac{\partial H_2}{\partial x_k} \tag{1}$$

where ϵ_{ijk} is the Levi–Civita tensor and H_1, H_2 are constants of motion. Then for any function $F(x_1, x_2, x_3)$ we have

$$\dot{F} = \sum_{ijk} \epsilon_{ijk} \frac{\partial F}{\partial x_i} \frac{\partial H_1}{\partial x_j} \frac{\partial H_2}{\partial x_k}. \tag{2}$$

This structure can be generalized to any number of variables $x_1, \ldots, x_n$ and functions $H_1, \ldots, H_{n-1}$ and this is what Nambu calls a generalized Hamiltonian dynamics. It provides an extension of Poisson algebras associated with Hamiltonian mechanics. For the case of three variables, he gives the example of Euler equations for the rigid body where the variables (x_1, x_2, x_3) are identified with the components of the angular momentum, H_1 is the square of the angular momentum, and H_2 the kinetic energy. He then discusses quantization, which leads to nonassociative algebraic structures.

In his last years, Yoichiro was interested in the formulation of hydrodynamics within this framework. This implied an infinite-dimensional generalization of his original scheme. He sent me the slides for two seminars he had given in Osaka, "A particle physicist's view of fluid dynamics" (subtitled "An old sake in a new cup") and "A new look at fluid dynamics". Shortly before the second seminar in the fall of 2013, I had attended a workshop in Cambridge, UK, where I discovered that physicists of the atmosphere, apparently independently, had made the connection between hydrodynamics and Nambu mechanics and had developed effective numerical algorithms based on it. I communicated the news to Yoichiro, who was very pleased by this concrete development and quoted their work [15] in the presentation. His comment on this seminar was

I just gave a talk at an international symposium on physics, Earth and Space sciences. I meant this as the last talk of my life, and I am relaxed now.

As I said, Nambu's mechanics is having an impact on mathematics, and on algebra in particular. I can refer to a recent paper [16] on Nambu's algebras, which deals with the finite-dimensional situation of the original 1973 paper. For the infinite-dimensional situation, the experts tell me that there are difficulties, initially unexpected, in developing a general theory[1].

I met Yoichiro for the last time in the summer of 2013 in Osaka, where I had the honor of inaugurating the newly instituted Nambu Colloquium. On this occasion we talked about various scientific subjects and he was very lively while the Japanese television station NHK was taking a film of our discussion. One topic that we discussed was the Titius–Bode law of planetary orbits, about which he was thinking in his usual original way. Afterwards we continued for a while by mail.

The last day of my visit I saw him at his home in Toyonaka near Osaka. He was not feeling well and could not come to the University. It was a moving moment for both of us. Maybe we had a premonition that this was the last time. In a message I received shortly after, he wrote

. . .it was a moving moment to see you again. It was fortunate of me to have got to know you. I have to confess that you are the one most close to me in terms of physical thinking, and most comfortable to talk to. . .

This is the friend I lost.

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[1] I thank Alberto De Sole for an illuminating discussion on this point.