QUANTUM FIELD THEORY

Edited by
FERDINANDO MANCINI

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Proceedings of the International Symposium in honour of
HIROOMI UMEZAWA
held in Positano, Salerno, Italy, June 5-7, 1985

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1986

NORTH-HOLLAND
AMSTERDAM · OXFORD · NEW YORK · TOKYO

ISBN: 0 444 87001 6

Published by:

North-Holland Physics Publishing
a division of
Elsevier Science Publishers B.V.
P.O. Box 103
1000 AC Amsterdam
The Netherlands

Sole distributors for the U.S.A. and Canada:

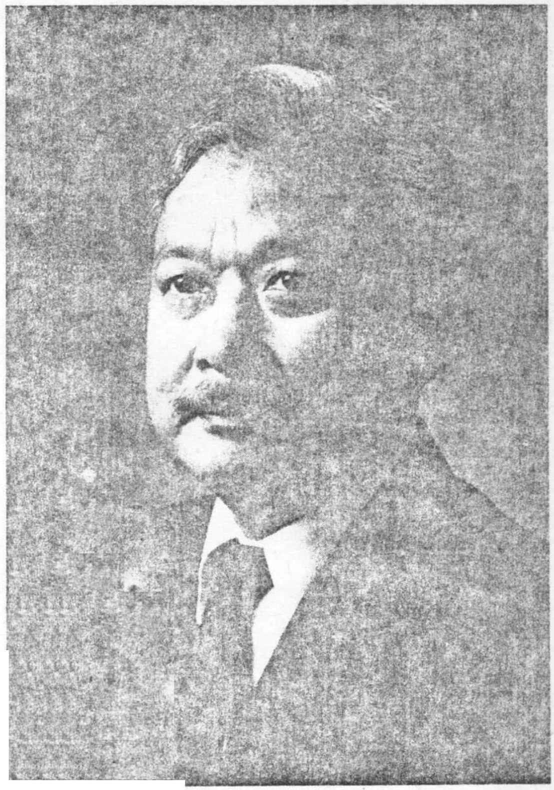
Elsevier Science Publishing Company, Inc.
52 Vanderbilt Avenue
New York, N.Y. 10017
U.S.A.

Library of Congress Cataloging in Publication Data

Quantum field theory.

"Contains the proceedings of the International Symposium on Quantum Field Theory, held at Positano from 5 to 7 June 1985"--Foreword.
Includes indexes.
1. Quantum field theory--Congresses. 2. Particles (Nuclear physics)--Congresses. 3. Condensed matter--Congresses. 4. Umezawa, H. (Hiroomi), 1924- .
I. Umezawa, H. (Hiroomi), 1924- . II. Mancini, Ferdinando. III. International Symposium on Quantum Field Theory (1985 : Positano, Italy)
QC174.45.A1Q3627 1986 530.1'43 86-5322
ISBN 0-444-87001-6 (U.S.)

PRINTED IN THE NETHERLANDS



Hiroomi Umezawa

FOREWORD

This book contains the Proceedings of the International Symposium on Quantum Field Theory, held at Positano from 5 to 7 June 1985. The Symposium was organized to honour the 60th birthday of Professor Hiroomi Umezawa.

In November 1983 I was at Edmonton; one afternoon, chatting with Hideki Matsumoto, we realized that very soon Umezawa would be sixty and we thought to celebrate the event by putting together his close friends in a small and intimate meeting. So we started to write down some names; very soon we realized that it would be impossible to limit the meeting to a small size, so many were the people related to Umezawa, and so wide was the area of his scientific interest. As Hiroomi says in his closing lecture, four periods can be distinguished in his life, related to the four countries Japan, Italy, United States, Canada (in chronological order). So we called Susumu Kamefuchi at Tsukuba and Nick Papastematiou at Milwaukee; the answer was very enthusiastic and we decided to organize an International meeting on Quantum Field Theory and its applications to High Energy and Condensed Matter Physics.

To both of these fields Umezawa has brought very important and fundamental contributions. To say it in his words, Umezawa has always lived with quantum field theory. This theory was born as a theory for elementary particles in high energy physics; his activity in this area, during the postwar years in Japan, is reviewed by Kamefuchi in the opening lecture. Very soon, through the works of many physicists, including Umezawa, it became clear that the area of applicability of quantum field theory is much larger than was previously thought. Investigations of systems with spontaneous breakdown of symmetry naturally led Umezawa to condensed matter physics. I have always thought that the boson theory of superconductivity, developed in those years, is a very clear example of his attitude towards physics: starting from a microscopic theory and by means of quantum field theory methods to succeed in computing observable quantities to be compared with experimental data. The recent application to magnetic superconductors has shown the usefulness of such a theory. Topological singularities existing in superconductivity then led him to investigate quantum objects in relativistic theories. The work in this area is reviewed in this book by Papastamatiou.

The interest in condensed matter physics by methods of quantum field theory naturally requires a formulation at finite temperature; as Ezawa told us in his lecture, also in this problem Umezawa has been one of the pioneers. Many years later, in the course of formulating a theory of superconductivity at finite temperature, it became clear that in order to take full advantage of methods of quantum field theory, it was necessary to extend the Matsubara formulation. Thermo Field Dynamics, reviewed in this book by Matsumoto, is now widely accepted, both in relativistic and non relativistic theories.

Theoretical physicists, coming from different countries, working on different areas, gathered at Positano: the Proceedings contain all the lectures delivered as well as contributed papers. Many areas of physics are represented, elementary particles in high energy physics, quantum relativity, quantum geometry, condensed matter physics, statistical mechanics; but all works are concerned with the use of the methods of quantum field theory. The first motivation of the meeting was to pay homage to a great physicist and a great friend; it was also an occasion in which theoretical physicists got together to discuss and to compare results in different fields. The meeting was very intimate; the relaxed atmosphere allowed constructive discussions and contributed to a positive exchange of ideas.

As a conclusion, I would say that in the course of years quantum field theory has developed enormously by acquiring a very rich structure and is now a theory commonly used, with great success, in many and different fields of physics; however, as we learned at Positano, the process is very far from being completed; not all the potential of the methods of quantum field theory has been exhausted. To many young physicists and students present at the meeting this might be the stimulating message.

ACKNOWLEDGEMENTS

During three days in June 1985 theoretical physicists from all over the world met in Positano to attend the International Symposium on Quantum Field Theory, the Proceedings of which are contained in this book.

The Symposium was sponsored by the University of Salerno, Italy, and by the University of Alberta, Canada. Many organizations gave their moral and financial support; I would like to acknowledge in a particular way the Istituto Italiano per gli Studi Filosofici, Naples, and the Yoshida Foundation for Science and Technology, Japan.

Professors Susumu Kamefuchi, Hideki Matsumoto and Nick Papastamatiou, who joined me in the Scientific Committee, were of vital importance for the realization and the great success of the Symposium. To them I wish to express my deepest and sincere acknowledgements.

The Symposium had the great fortune of having among its enthusiastic supporters the Rector of the University of Salerno, Professor Vincenzo Buonocore, the Dean of Science of the University of Alberta, Professor W.J. McDonald, the President of the Istituto Italiano per gli Studi Filosofici, Dr. Gerardo Marotta; to them my appreciation and gratitude.

At various stages of my work, I enjoyed the collaboration of many friends whose contributions have been extremely important for the Symposium and are highly appreciated. I would like to thank the Local Organizing Committee: Professors S. De Filippo, M. Fusco-Girard, P. Sodano and G. Vitiello; the continuous encouragement of Professor Maria Marinaro was essential; special thanks go to Dr. Ileana Rabuffo, who helped me in the preparation of these proceedings. A final word of acknowledgement to my wife who helped me in the general organization and assisted me on so many occasions; to her my deepest gratitude.

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QUANTUM FIELD THEORY IN POSTWAR JAPAN

— Early Works of H. Umezawa —

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The paper reviews the research in quantum field theory made in postwar Japan, with emphasis upon Professor H. Umezawa's work. Its contents are as follows: 1 prologue, 2 the initial conditions, 3 a little about H.U., 4 C-meson theory, 5 method of mixed fields I — photon self-energy, 6 method of mixed fields II — vacuum polarization, 7 renormalization theory I — a prehistory, 8 renormalization theory II — renormalizability, 9 miscellanea and 10 epilogue.

1. PROLOGUE

It is a great honour for me to give this opening lecture of the symposium to talk about the research in quantum field theory (QFT), and in particular, in the divergence problem, made in postwar Japan, the later part of which I was fortunate to witness. In my opinion this kind of talk is appropriate for this occasion for the following two reasons. First, the decade 1945-1955 was the period during which Japan played, in a sense, a leading role in the research of QFT; three great names thereof were H. Yukawa, S. Tomonaga and S. Sakata. And second, it was precisely in this period that Professor Umezawa started his research career and immediately acquired an international recognition. I believe therefore that it is worth summarizing, on this occasion, Professor Umezawa's early important contributions to QFT, which may or may not be well known to the younger generations.

2. THE INITIAL CONDITIONS

I would now like to start by giving a brief review of the war-time activities in Japan, in order to make clear the initial conditions with which Umezawa started his research career. In my opinion the reason why Japan, just after the war, was in an advantageous position in the research of QFT is that even during the war the so-called Research Group of Elementary Particle Theory, led by Yukawa, Tomonaga and Sakata, managed to continue their work. They organized a series of the Meson Theory Discussion Meetings, and discussed there not only Yukawa's meson theory, but also QFT in general. Influenced mostly by M. Taketani who is a kind of scientist-philosopher, they were very methodology-minded. Thus, analysing the situation in which the then QFT and elementary particle physics were placed, they regarded various difficulties encountered there as arising from the following three causes:

(1) fundamental defects inherent in QFT;

(2) inadequacy of the models adopted for elementary particles and their interactions;

(3) inadequacy of the approximation methods adopted in QFT.

These different attitudes towards the situation then made them take the corresponding, different approaches (1), (2) and (3).

Approach (1)

Yukawa was the protagonist in research of this kind. Like Heisenberg[1], he was very conscious of the limit of applicability of QFT, and tried to find a new theory on the basis of new concepts; that is, he was acutely feeling the necessity of a new paradigm. As a researcher he was, in this sense, a "revolutionary". Until the end of his life, he firmly held the belief that all difficulties of the theory would be solved by relating them to the structure of space-time. From about 1935 onwards he often drew a circle on the blackboard; people used to call it "Yukawa's maru (circle)". His intention was to define transition amplitudes, not on a flat surface as was customary in the Heisenberg-Pauli formalism of QFT[2], but instead on a curved, e.g., spherical surface[3]. It is, of course, very difficult to formulate such an idea, because Yukawa's maru contains mutually time-like points. At about this time Dirac also considered "generalized transformation functions" of a similar kind[4] (cf. also his many-time theory[5]; three forms of relativistic dynamics[6]).

This idea was then taken over by Tomonaga. While Yukawa was a revolutionary as a researcher, Tomonaga used to say that he was a "non-reactionary conservative". Thus he transformed the revolutionary circle into a conservative shape like a flying saucer, where all points are mutually space-like. As is well known, this led him to the celebrated super-many-time formalism of QFT, that is, the Tomonaga-Schwinger formalism. The first paper on this work was published in Japanese during the war[7]: this was then translated into English after the war and published in Progress of Theoretical Physics (P.T.P)[8], a new journal created by Yukawa in 1946. On the other hand, Yukawa himself developed the above-mentioned idea, after the war, into his theory of non-local fields[9] and then to the theory of elementary domains[10].

Approach (2)

In the problem of models of particles and interactions Sakata was the central figure. One of the most important achievements made during the war is the so-called two-meson hypothesis proposed by Sakata and Tanikawa in April, 1942[11]. In order to make Yukawa's meson compatible with the then available cosmic ray data they introduced a second meson, now known as μ- meson. The existence of the two kinds of mesons, π and μ, was experimentally confirmed after the war by the Bristol group[12].

Sakata also tried to solve the divergence difficulty of the electromagnetic self-energy of the electron by revising the model, i.e., by introducing a new, neutral scalar field, called C-meson field. I will come back to this in sect. 3.

Approach (3)

Being very good in mathematics, Tomonaga was unrivalled in this field. Since the coupling constant in Yukawa's meson theory is very large, the perturbation approximation obviously does not lead to good answers. Even since the time that he worked with Heisenberg in Leipzig, i.e., 1937-1939, Tomonaga had often discussed various approximation methods. As for the strong-coupling approximation he did the same thing as Wentzel[13], but did not publish the work since Wentzel's paper appeared in the meantime. So he turned to the intermediate coupling approximation[14]. This problem was taken up a number of times after the war[15].

Tomonaga also discovered another approximation method which was later rediscovered by Tamm and Dancoff[16]. He proposed this method in his contribution to Heisenberg's 40th birthday Festschrift. However, having found a minor error in the paper, he withdrew it by sending a telegram to von Weizsäcker, the editor. Later he often regretted this withdrawal.

The foregoing is a quick summary of the war-time activities, and I hope that it has given you some idea about the general background in which Professor Umezawa started his research of QFT. As for the postwar activities I shall hereafter discuss them in connection with Professor Umezawa's works.

3. A LITTLE ABOUT H.U.

Hiroomi Umezawa was born in Sapporo in 1924 as the 6th son to Dr. Jun-ichi Umezawa: *he is always proud of the fact that he was born and grew up together* with Quantum Mechanics. Of his five prominent brothers (no sisters), four are scientists, and one is a science administrator. Like Dirac he studied electrical engineering (not at Bristol but) at Nagoya University. As just a 3rd year undergraduate he, however, started attending Professor Sakata's seminar at the Physics Department of the same university. Graduating from the university in 1946, he joined Sakata's group and started his research career as a collaborator of Sakata's. Their works done in the following years (1947-1953) centre around the divergence problem in QFT. And in reviewing those works I find it convenient to group them into three stages; that is, those of

C-meson theory, method of mixed-fields and renormalization theory. In the following I shall try to review these three stages one by one in the chronological order.

In passing I also tried to see if there were any works done before this first stage. The oldest material I have found is this picture (A), but no

Picture A
(~1941)

Picture B
(~1946)

physics papers seem to have been published at this time. His publications started appearing at the time when he looked like this (B). Since then he has been very productive all the time, and the most up-to-date list of publications consists of 17 pages plus one more for preprints. My talk covers only the first 2-3 pages. Some of his later papers will be taken up by Drs. H. Ezawa and H. Matsumoto in their talks.

In addition to these research papers he has written two books in English, each providing a summary of his works done up to the time of publication. The first was published in 1956: H. Umezawa, *Quantum Field Theory* (North-Holland, 1956), and the second in 1982: H. Umezawa, H. Matsumoto and M. Tachiki, *Thermo Field Dynamics and Condensed States* (North-Holland, 1982). In 1953 he wrote, however, a book in Japanese: H. Umezawa, *Soryushiron* or The Theory of Elementary Particles (Misuzu Shobo, 1953); most of its contents were later inherited by the English descendant — *Quantum Field Theory*. Again my talk is concerned only with a small part of this book. I expect that Dr. Matsumoto will talk about the second book.

4. C-MESON THEORY

How to deal with the ultraviolet divergences was the central problem of QFT in those days. Near the end of the war, Sakata was staying in the countryside far from Nagoya, escaping from air raids. And it is at this place that he got the idea of the C-meson theory, with C for cohesive force.

Historically, the idea of cohesive force is rather old. The first literature we can trace is Poincaré's 1905 paper, titled "On the dynamics of the electron"[17]. It is then followed by a number of papers which try to make the Coulomb force non-singular at the origin, such as Mie[18], Born[19] and Bopp[20]. It appears, however, that Sakata was directly influenced by Bopp. As is easily shown, Bopp's theory is equivalent to introducing a neutral vector field with negative norm, so that $e^2/r \to e^2/r - g^2 e^{-\kappa r}/r = e^2(1-e^{-\kappa r})/r$ if $e^2 = g^2$. On the other hand, Stueckelberg pointed out, within the framework of classical theory, that a neutral scalar field with positive norm can play the same role[21]. Stueckelberg's work seems to have remained unnoticed, or at least, it was never quoted, by Sakata and his collaborators.

At any rate, Sakata's C-meson is a quantized version of Stueckelberg's neutral scalar meson in interaction with all charged particles. After the war the theory was vigorously pursued by Sakata, Hara and others[22]. According to them the conditions for the cancellation of the self-energy divergences due to the electromagnetic and C-meson fields are given as follows;
for a charged, spin-1/2 field with $H_{int} = f(\bar{\psi}\psi)\phi$,

$$f^2 = 2e^2 \ ; \tag{4.1}$$

for a charged, spin-0 field with $H_{int} = fm_\psi(\psi^+\psi)\phi + g^2(\psi^+\psi)\phi^2$,

$$f^2 = 3e^2(1 + m_c^2/m_\psi^2) \ , \quad g^2 = 3e^2 \ ; \tag{4.2}$$

for a charged, spin-1 field,

similar but more complicated conditions;

where ψ and ϕ stand for a charged and C-meson fields, respectively. As is seen above, the f- and g- couplings are not universal, contrary to the e-coupling. We should mention in this respect that Pais also proposed the same idea at almost the same time[23].

Sakata (and Pais) tried also to explain the P-N mass difference on this basis by assuming $m_c \sim 100\ m_e$. The theory was then applied to the Lamb shift[24]. And it was at this stage that Umezawa made his first appearance on the scene.

According to the testimony by Umezawa, when he joined the group, Hara asked him to work together on the Lamb-shift calculation, and the result was reported by Hara at the spring meeting of the Physical Society of Japan (PSJ), 1947. So this must be Umezawa's Opus 1: I tried to find this report in PSJ journal, P.T.P. etc., but in vain. Instead I found a short report, entitled "On the interaction between a negative meson and a proton"[25], which should therefore be added to his list of publications as No. Zero. In this report they discuss the effect of C-meson on the K-orbit of a negative meson (around a proton). As you know, in those days the capture probability of negative mesons by matter was an important problem in connection with the question of whether cosmic ray mesons are identical with Yukawa's particles. Ogawa, on the other hand, tried to find some possible effects of C-mesons on cosmic ray showers[26].

Sakata's C-meson theory had also played an important role in Tomonaga's discovery of renormalization theory. I will revert to this in sect. 7.

5. METHOD OF MIXED FIELDS I — Photon Self-Energy

This is the method advocated by Sakata as a further extension of the idea underlying the C-meson theory. According to him, part of the difficulties in QFT are due to our overlooking the close interconnections between various elementary particles. He says: "Even when electromagnetic phenomena of the electron are concerned, one should take into account not only the electron and photon fields but also all other fields that are directly or indirectly interacting with the two fields: the success of the C-meson theory provides a good example. One should consider the system of elementary particles as a whole".

For us today this is an obvious thing to do, but in those days there prevailed a tendency to treat the electron by QED, the meson by the meson theory, and so on. Now, Sakata's philosophy leads us immediately to an attempt at cancelling divergences by mixing, i.e., by taking into account the contributions from all possible fields that are conceivable in a given problem. In the case of QED the electron self-energy was made finite by means of the C-meson field, but there still remains another type of divergence, that is, the one in photon self-energy, or more generally, in vacuum polarization. Thus what to do with this divergence was the most pressing problem for the Sakata group in 1947, and this task was entrusted to young Umezawa. According to him, this was the first (and in fact the last) problem given him by Sakata, and he beautifully met Sakata's expectations.

In carrying out this work Umezawa organized a small group, which consisted of J. Yukawa, E. Yamada, and later R. Kawabe. They appear to have worked very hard: this may be seen from the fact that more than a dozen papers were published on this problem in a year or so. In the beginning Umezawa studied