Introduction to Axiomatic Quantum Field Theory

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Authorized translation from the Russian manuscript by
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Edited by Stephen A. Fulling

1975
W. A. Benjamin, Inc.
Advanced Book Program
Reading, Massachusetts

London · Amsterdam · Don Mills, Ontario · Sydney · Tokyo

Introduction to Axiomatic Quantum Field Theory
First English Edition, 1975
Originally published in 1969 as
Osnovy aksiomaticheskogo podkhoda v kvantovoy teorii polya
by Izdat'elstvo "Nauka," Moscow

Library of Congress Cataloging in Publication Data
Bogoliubov, Nikolai Nikolaevich, 1909-
Introduction to axiomatic quantum field theory.

(Mathematical physics monograph series ; 18)
Translation of Osnovy aksiomaticheskogo podkhoda v kvantovoĭ teorii polia.
Bibliography: p.
Includes index.
1. Quantum field theory. I. Logunov, Anatolii Alekseevich, joint author. II. Todorov, Ivan T., joint author. III. Title.
QC174.45.B5913 530.1'43 72-5554

American Mathematical Society (MOS) Subject Classification Scheme (1970): 81A17

ABCDEFGHIJ-HA-7987654

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Editor, A. S. Wightman

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PREFACE

At the end of 1960 we made plans to write a monograph about the general principles of quantum field theory and their experimental implications. We intended primarily to give an account of the progress of the theory of dispersion relations since the appearance of the book of Bogolubov, Medvedev and Polivanov ([BMP][†]). As an introduction we wanted to include a review of the various approaches to axiomatic field theory. This introduction had to cover not only the formulation of Bogolubov, Medvedev and Polivanov, based on the apparatus of functional derivatives of the S-matrix and the condition of microcausality, but also the field formulation associated with the names of Wightman, Haag, Lehmann, Symanzik, Zimmermann, and others. In the course of the work the tasks (and with them the size) of the introduction grew larger and larger,[††] until eventually it developed into this book.

Meanwhile two excellent books on the general theory of quantum fields, [SW] and [J], appeared (and were translated into Russian). They are written by theoreticians who helped lay the foundations of the "field" aspect of the subject.

[†]Our system of bibliographical references is explained in the Introduction.

[††]An intermediate stage of this project was reflected in the lectures of Todorov (1964). (See also Todorov (1965).)

In addition to the topics covered in these books, the present work covers the S-matrix formulation of the basic principles of the theory and the interrelationships of the various formulations (Part Four). Also, in this book more attention is paid to the group-theoretical aspects of the subject: we present the necessary information about the Wigner theory of the unitary representations of the Poincaré group; the discrete transformations are considered in detail; the impossibility of describing a broken symmetry by a time-dependent unitary operator in a field theory with nondegenerate vacuum is demonstrated.

The volume has a predominantly theoretical character; this, naturally, has influenced its style. However, we have not lost the hope that it will be followed by a second volume which will deal with the theory of dispersion relations, asymptotic equalities among amplitudes, and other experimentally verifiable consequences of the general principles of quantum field theory. (Among such applications, the present volume contains only the TCP theorem and the theorem on the connection between spin and statistics.)

The book is directed to theoretical physicists and mathematicians interested in the general problems of quantum field theory. Although we have tried to make the presentation of the problems self-contained, we cannot recommend this book for beginners in quantum theory. Besides an acquaintance with a standard course in quantum mechanics it would be useful to have an elementary knowledge of quantum field theory (the material, for example, of the book [HT] or the first three chapters of [BS]).

The auxiliary mathematical tools which go beyond the content of undergraduate courses for physicists are given (schematically) in the text. They include some concepts of

functional analysis, the theory of distributions, and the theory of group representations.

It is our pleasant duty to thank V.S. Vladimirov, M.B. Mensky and A.I. Oksak for a number of useful remarks and Mrs. L.G. Popova for her help in the preparation of the manuscript.

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Authors' Preface to the English Edition

One advantage of the rigorous results in quantum field theory is that they have a somewhat longer lifetime than most of the fashionable work in elementary particle physics. So we did not have to write the book anew in the year and a half which it took for the English translation to be prepared. Nevertheless, we took the opportunity in the meantime not only to correct a number of misprints and minor inaccuracies which were left in the Russian edition, but also to introduce some new material and to make some more substantial alterations.

The additions incorporate three new appendices (D, F, and G) and a new Part (Six). Significant changes were made in Appendix B, Chapters 16 and 17, and Sec. 7.2. The new material includes a treatment of infinite-component fields in the axiomatic framework; in particular, the technique of homogeneous functions of two complex variables is introduced and the invalidity of the spin-and-statistics and TCP theorems for infinite-component fields is demonstrated. A brief review of the recent work of Glimm and Jaffe on two-dimensional models is given in the new Chapter 25.

The authors have the pleasure of thanking Professor A.S. Wightman, editor of the Benjamin series, on whose initiative the English translation of this book was undertaken and whose continuous and active support made this edition possible. We should like to thank Dr. S.A. Fulling whose work on the

English edition greatly exceeded the usual task of a translator. His competent critical reading of the whole manuscript helped to correct a number of errors; he also made useful suggestions for the final organization and appearance of the material in the English edition. The close collaboration between Dr. Fulling and the authors during the work on the English translation was made possible because of the hospitality extended to one of the authors (I.T.T.) at the Institute for Advanced Study in Princeton in this period. It is his pleasure to thank Professor C. Kaysen and the members of the Faculty of Natural Sciences of the Institute for their kind hospitality.

Translators' Preface

As the authors remark in their preface, this book is probably unique among English translations of Russian works for the close collaboration which was possible between the translators and one of the authors, Dr. I.T. Todorov. On the one hand, various revisions were made by him on behalf of the authors, so that the book is really a second edition as well as a translation. From the translators' point of view, the opportunity to consult with the author and to submit the translation for his inspection made a much freer translation possible, without risk of distorting the meaning of the text. Also, a few suggestions of ours, mostly with the aim of making the text clearer to the English-speaking reader, could be incorporated without the use of "translators' notes". We are very grateful for Dr. Todorov's assistance.

The reader is warned that in the numbering of chapters, equations, and so forth translation invariance is violated. Chapters and appendices have been numbered (or lettered) consecutively throughout the book, whereas in the Russian edition the numeration starts over at the beginning of each Part of the book. This change considerably simplifies internal references; in particular, theorems, equations, and so on are now identified by double numbers instead of the triple numbers of the original.

One of us (S.A.F.), who oversaw the preparation of the manuscript, wishes to acknowledge the patient work of Mrs. B. Cruser, Mrs. W. Snook, Miss C. Spangenberg, Miss K. Jones and Mr. P.W. Liu on this task, and to thank Dr. A. Blaer and Messrs. N. Ó Murchadha, R. Wald, J. Friedman, and A. O'Connor for help in proofreading (including a few editorial suggestions) Professor H. Ezawa, editor of the Japanese translation, supplied a list of corrections to the original. We are also grateful to Professor A.M. Jaffe for some helpful remarks on Chapter 25. Many other people associated with Princeton University and with the Institute for Advanced Study gave assistance at critical moments, particularly Professor A.S. Wightman. Finally, S.A.F. is grateful to the National Science Foundation for permission to undertake this work during the tenure of a Graduate Fellowship.

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