ELECTROWEAK THEORY

The electroweak theory unifies two basic forces of nature: the weak force and electromagnetism. This achievement is comparable to Maxwell's unification of electricity and magnetism. The theory made numerous predictions that have been confirmed by experiments. This book is a concise introduction to the structure of the electroweak theory and its applications.

Electroweak Theory describes the structure and properties of field theories with global and local symmetries, leading to the construction of the standard model. The greater part of the book explains the basic predictions of the theory. It describes the new particles and processes predicted by the theory, and compares them with experimental results. Among the topics covered are neutral currents, the properties of W and Z bosons, the properties of quarks and mesons containing heavy quarks, neutrino oscillations, CP-asymmetries in K, D, and B meson decays, and the search for Higgs particles.

The book contains sections guiding the reader through the complicated calculations of Feynman diagrams, such as box and penguin diagrams. There are discussions of the results and their relevance to physical phenomena. Each chapter contains selected problems, stemming from the long teaching experience of the author, to supplement the text. This will be of great interest to graduate students and researchers in elementary particle physics. Password protected solutions will be available to lecturers at www.cambridge.org/9780521880987. This title, first published in 2007, has been reissued as an Open Access publication on Cambridge Core.

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To my wife Sharon
and our children
Anthony, Christina-Maria, and John

Contents

Cambridge University Press & Assessment
978-1-009-40238-5 — Electroweak Theory
E. A. Paschos
Frontmatter
More Information

Preface

The aim of the book is to introduce the electroweak theory and the methods that have been developed for calculating physical processes. To this end it was decided to divide the book into three major parts.

I. The road to unification

This part gives a general view of early developments when the theory was based on numerous empirical rules. These topics are extensively discussed in older books on weak interactions, and I selected a few topics among them, such as form factors, CVC, and PCAC, in order to give a general impression of how the field developed. It should serve as an introduction to a few topics from the early period of weak interactions and as a guide to articles and texts. Appreciation of the first part requires familiarity with the methods developed at that time. The readers who find this part too brief or difficult may proceed to the second part, where gauge theories are introduced.

II. Field theories with global or local symmetries

This part presents field theories based on continuous symmetries and guides the student to the electroweak theory based on the group SU(2) × U(1). Special effort has been made to present it in a simple and pedagogical way. For this reason the chapters are short and accompanied by references that the reader or lecturer can consult.

III. Experimental consequences and comparisons

The third part of the book covers some of the exciting discoveries that took place in the process of verifying the electroweak theory. To date, there has been no book dedicated to the study of the electroweak theory and its developments over the past

30 years. Several textbooks cover special chapters, but an introductory overview for graduate students, both theorists and experimentalists, is still missing.

The weak interactions, because they are weak, allow perturbative calculations that are very accurate. Since the introduction of the theory (1967), there have been several discoveries that have stimulated intensive research activity. These discoveries include

- neutral currents
- the charm quark, bottom quark, and top quark
- neutrino properties and their interactions (oscillations)
- intermediate gauge bosons
- heavy quarks (bottom and top)
- CP violation in K- and B-meson systems

There is hardly a book in which all the topics are discussed together. One reason for this lack is that the discoveries happened every few years and older textbooks could not cover them. This book has been written over several years and includes the new topics. The author has worked on several topics and contributed to them.

In several seminars it became clear that advanced students were asking many questions on how to calculate specific topics; for example box and penguin diagrams, processes with mixings of Majorana neutrinos, CP-violating amplitudes, etc. The outcome of efforts to answer these questions is the collection of chapters which form the book. The answers to several such questions comprise sections that should help the reader to find his or her way through the ideas and the calculations and to go further to study the original papers. Some topics like neutral current calculations may appear standard, but are again relevant and useful for the neutrino oscillation and long-base-line experiments. The problems are an integral part of the book and help to clarify the sections of the book or present specific cases as examples.

The theory has still not been completely verified, because the Higgs particles have not been discovered. The theory may belong to a larger grand unified theory, which tempted me to include chapters on future developments. The book could have been made longer by including more chapters on QCD, grand unification, supersymmetry, etc. I tried to avoid this temptation and concentrated on topics that have become standard themes of the electroweak theory.

I am enormously grateful to those who generously took the time to read the manuscript and offered corrections and technical support. The writing of a book relies on the support of many friends and colleagues.

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