

Preface

This book has been developed from the lecture notes of a course in Advanced Quantum Mechanics given by the authors at the Politecnico of Torino for students of physical engineering, who, even though oriented towards applied physics and technology, were interested in acquiring a fair knowledge of modern fundamental physics. Although originally conceived for students of engineering, we have eventually extended the target of this book to also include students of physics who may be interested in a comprehensive and concise treatment of the main subjects of their theoretical physics courses. What underlies our choice of topics is the purpose of giving a coherent presentation of the theoretical ideas which have been developed since the very beginning of the last century, namely special relativity and quantum mechanics, up to the first consistent and experimentally validated quantum field theory, namely quantum electrodynamics. This theory provides a successful description of the interaction between photons and electrons and dates back to the middle of the last century.

Consistently with this purpose (and also for keeping the book within a reasonable size), we have refrained from dealing with the many important ideas that have been developed in the context of quantum field theory in the second part of the last century, although these are essential for a satisfactory understanding of the current status of elementary particle physics. A prominent example of such developments is the so-called standard model, in which for the first time all the (non-gravitational) interactions and the fundamental particles (quarks and leptons) were coherently described within a unified field theory framework. Looking at the past, however, one recognizes that this achievement has its very foundations in the two building blocks of any modern physical theory: special relativity and quantum mechanics, which have been left essentially unaffected by the later developments.

Quantum electrodynamics has provided a basic reference for the formulation of the standard model and in general for any field theory description of the fundamental interactions. In particular, a major role is played in quantum electrodynamics by the concept of gauge symmetry which is the guiding principle for the correct description of the interaction. Likewise, the standard model too, as a

quantum field theory, is based on a suitable gauge symmetry, which is a non-abelian extension of that present in quantum electrodynamics.

On the basis of these considerations, we hope the concise account of quantum electrodynamics that we give at the end of our book can provide the interested reader with the necessary background to cope with more advanced topics on theoretical particle physics, in particular with the standard model.

The present book is intended to be accessible to students with only a basic knowledge of non-relativistic quantum mechanics.

We start with a concise, but (hopefully) comprehensive exposition of special relativity, for which we have added a chapter on the implications of the principle of equivalence. Here we have a principle whose importance can be hardly overestimated since it is at the very basis of the general theory of relativity, but whose discussion in a class, however, requires no more than a couple of hours. Nevertheless, this issue and its main implications are rarely dealt with even in graduate courses of physics. Can general relativity be totally absent from the scientific education of a student of physics or engineering? Of course it can be, as far as the full geometrical formulation of theory is concerned. However it is well known that many technological devices, mainly the GPS, require for their proper functioning to consider the corrections implied by the Einstein's theories of special and general relativity. Our account of the principle of equivalence and its main implications will allow us to derive in a rather non-rigorous but intuitive way the concepts of connection, curvature, geodesic lines, etc., emphasizing their intimate connection to gravitational physics.

Thereafter, in Chaps. 4 and 7, we give the basics of the theory of groups and Lie algebras, discussing the group of rotations, the Lorentz and the Poincaré group. We also give a concise account of representation theory and of tensor calculus, in view of its application to the formulation of relativistically covariant physical laws. These include the Maxwell's equations, which we discuss in their manifestly covariant form in Chap. 5.

In Chap. 6, anticipating part of the analysis which will be later developed, we discuss the quantization of the electromagnetic field in the radiation gauge. We thought it worth illustrating this important example early because it clarifies how the concepts of photon and of its spin emerge quite naturally from a straightforward application of special relativity and quantum theory in a field theoretical framework.

In Chap. 8 we review the essentials of the Lagrangian and Hamiltonian formalisms, first considering systems with a finite number of degrees of freedom, and then extending the discussion to fields. Particular importance is given to the relation between the symmetry properties of a physical system and conservation laws.

The last four chapters are devoted to the development of quantum field theory. In Chap. 9 we recall the basic construction of quantum mechanics in the Dirac notation. Eventually in Chap. 10, we study the quantum relativistic wave equations emphasizing their failure to represent the wave function evolution in a consistent way.

In Chap. 11 we perform the quantization of the free scalar, spin 1/2 and electromagnetic fields in the relativistically covariant approach. The final goal of this analysis is to provide the quantum relativistic description of fields in interaction, with particular reference to the interaction between spin 1/2 fields (like an electron) and the electromagnetic one (quantum electrodynamics). This is done in Chap. 12 in which the graphical description of interaction processes by means of Feynman diagrams is introduced. After the classical example of the tree-level processes, we start analysing the one-loop ones where infinities make their appearance. We then discuss how one can circumvent this difficulty through the process of renormalization, in order to obtain sensible results. We shall however limit ourselves to give only a brief preliminary account of the renormalization programme and its implementation at one-loop level.

As the reader can realize, there is scarcely any ambition on our side to develop various topics in an original way. Our goal, as pointed out earlier, is to give in a single one-year course the main concepts which are at the basis of contemporary theoretical physics.

A Note on the Bibliography

It is almost impossible to give even a short account of the many textbooks covering some of the topics which are dealt with in this book. Any textbook on relativity or elementary particle theory covers at least a part of the content in our book. We therefore limit ourselves to quote those excellent standard textbooks, which have been for us a precious guide for the preparation of the present work, referring them to the interested reader in order to deepen the understanding of the topics dealt with in this book.

From Special Relativity to Feynman Diagrams

A Course in Theoretical Particle Physics for Beginners

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2016, XVI, 601 p., Hardcover

ISBN: 978-3-319-22013-0