Springer Tracts in Modern Physics
Volume 201

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Springer Tracts in Modern Physics

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Heavy Quark Effective Theory

With 72 Figures

Springer

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Cataloging-in-Publication Data applied for

Physics and Astronomy Classification Scheme (PACS):
12.39.Hg, 12.38.Bx

ISSN print edition: 0081-3869
ISSN electronic edition: 1615-0430
ISBN 3-540-20692-2 Springer-Verlag Berlin Heidelberg New York

Springer-Verlag is a part of Springer Science+Business Media

springeronline.com

Typesetting: by the author using a Springer LaTeX macro package
Cover concept: eStudio Calamar Steinen
Cover production: *design &production* GmbH, Heidelberg

Printed on acid-free paper SPIN: 10791166 56/3141/jl 5 4 3 2 1 0

Preface

Heavy quark physics is one of the most rapidly progressing areas of high energy physics, both experimentally and theoretically. Experiments at the B-factories at SLAC and KEK are producing a lot of information about decays of B-mesons, with high statistics and low systematic errors. Therefore, a better theoretical understanding of the properties of B-mesons is very important. An understanding of strong-interaction effects in weak decays is necessary for extracting fundamental electroweak parameters (such as elements of the Kobayashi–Maskawa mixing matrix) from experimental data on these decays. Moreover, investigation of the B-meson – the simplest non-trivial hadron, the QCD hydrogen atom – is interesting in its own right.

In this book, we shall discuss properties of hadrons with a single heavy quark, b or c; the t quark decays before it can form a hadron, and it is not interesting for our purposes. In the case of hadrons containing a c quark, $\Lambda_{\mathrm{QCD}}/m_{\mathrm{c}}$ corrections can be rather large. The applicability of the theory for hadrons containing b is much better. The physics of mesons consisting of a heavy quark and a heavy antiquark ($\bar{\mathrm{c}}\mathrm{c}$, $\bar{\mathrm{b}}\mathrm{b}$, $\bar{\mathrm{b}}\mathrm{c}$) is essentially different, and will not be discussed here. Note that B_{c} mesons can be, to some approximation, described by the methods discussed in this book. However, the expansion parameter $m_{\mathrm{c}}/m_{\mathrm{b}} \approx 1/3$ is not very small, and the accuracy would be poor.

Heavy quark effective theory (HQET) is an effective field theory constructed to reproduce the results of QCD for problems with a single heavy quark with mass m, expanded to some order $(k/m)^n$, where $k \ll m$ is the characteristic momentum in the problem. To the leading order in $1/m$, it has symmetries which are not explicit in the original QCD Lagrangian. These symmetries relate various matrix elements involving heavy hadrons. HQET considerably simplifies lattice simulations with heavy quarks. The considerable progress in the theory of hadrons containing a heavy quark during the last decade is largely due to HQET.

In this book, we shall discuss the properties of HQET as a quantum field theory and the methods used for calculating Feynman diagrams in HQET. Some knowledge of QCD (see, e.g., the textbook [15]) is needed for understanding the text. However, knowledge of methods of calculation of multiloop diagrams is not assumed. We shall discuss such methods for QCD and HQET in parallel (see [9] for more details).

Chapter 1 gives an overview of basic experimental facts about mesons and baryons containing a b or c quark and a qualitative discussion of some of their properties. Then the HQET Lagrangian (Chaps. 2–4) and bilinear quark currents (Chaps. 5–7) are discussed in detail. Finally, Chap. 8 discuses some facts and hypotheses about the behaviour of perturbative series in HQET at high orders.

We shall discuss a few of the most fundamental applications in great detail, rather than provide a long list of results without derivations. Some of the material in this book was used in lecture courses, and all calculations were actually performed in the classroom. Such an explicit approach should be appropriate for those readers who wish to develop skills for solving similar problems. Results which cannot be derived during a lecture are in most cases not included. Readers who want to do non-trivial calculations are advised to use computer algebra (see, e.g., [8]).

Larger areas which are omitted from this book, owing to space and time constraints, are inclusive decays of heavy hadrons (see, e.g., [16, 1, 17]) and their interactions with soft pions (see, e.g., [20, 2]). Remarkable progress has been made in recent years in both of these areas. Also, we shall not discuss other effective field theories, such as non-relativistic QCD (used for heavy-quark–antiquark systems) and soft-collinear effective theory (used for decays of hadrons containing a heavy quark producing energetic light hadrons). These theories are under active development, and a firm knowledge of a simpler effective theory, HQET, is invaluable for understanding these more complicated theories.

For more information about applications of HQET, see the book [13] and the reviews [1, 3, 4, 5, 6, 7, 10, 11, 12, 14, 16, 17, 18, 19].

I am grateful to P.A. Baikov, A.E. Blinov, D.J. Broadhurst, K.G. Chetyrkin, A. Czarnecki, A.I. Davydychev, G.P. Korchemsky, J.G. Körner, S.A. Larin, T. Mannel, K. Melnikov, S.V. Mikhailov, M. Neubert, T. van Ritbergen, V.A. Smirnov, F.V. Tkachov, N.G. Uraltsev, A.I. Vainshtein, and O.I. Yakovlev for numerous illuminating discussions of problems discussed in this book.

Novosibirsk, February 2004 *Andrey Grozin*

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