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Cambridge University Press
978-0-521-52147-5 - The Experimental Foundations of Particle Physics, Second Edition
Robert N. Cahn and Gerson Goldhaber
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THE EXPERIMENTAL FOUNDATIONS OF PARTICLE PHYSICS

Second Edition

Our current understanding of elementary particles and their interactions emerged from break-through experiments. This book presents these experiments, beginning with the discoveries of the neutron and positron, and following them through mesons, strange particles, antiparticles, and quarks and gluons. This second edition contains new chapters on the W and Z, the top quark, B-meson mixing and CP violation, and neutrino oscillations.

This book provides an insight into particle physics for researchers, advanced undergraduate and graduate students. Throughout the book, the fundamental equations required to understand the experiments are derived clearly and simply. Each chapter is accompanied by reprinted articles and a collection of problems with a broad range of difficulty.

ROBERT CAHN is a Senior Physicist at the Lawrence Berkeley National Laboratory. His theoretical work has focused on the Standard Model, and, together with his collaborators, he developed one of the most promising methods for discovering the Higgs boson. As a member of the BaBar Collaboration, he participated in the measurement of CP violation in B mesons.

GERSON GOLDHABER is a Professor in the Graduate School at the University of California at Berkeley, and Faculty Senior Physicist at the Lawrence Berkeley National Laboratory. He is co-discoverer of the antiproton annihilation process, the Bose–Einstein nature of pions, the J/Psi particle and psion spectroscopy, charmed mesons, and dark energy.

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For
our grandchildren
Zachary, Jakob, Mina, and Eve

and
Benjamin, Charles, and Samuel

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Preface to the Second Edition

In the twenty years since the first edition, the promise of the Standard Model of Particle Physics has been fulfilled. The detailed behavior of the W and Z bosons did conform to expectations. The sixth quark finally arrived. The pattern of CP violation in B mesons fit convincingly the predictions based on the Kobayashi–Maskawa model. These three developments require three new chapters. The big surprise was the observation of neutrino oscillations. Neutrino masses and oscillations were not required by the Standard Model but are easily accommodated within it. An extensive fourth new chapter covers this history.

Though the neutrino story is not yet fully known, the basics of the Standard Model are all in place and so this is an appropriate time to update the Experimental Foundations of Particle Physics. We fully anticipate that the most exciting times in particle physics lie just ahead with the opening of the Large Hadron Collider at CERN. This Second Edition provides a recapitulation of some 75 years of discovery in anticipation of even more profound revelations.

Not only physics has changed, but technology, too. The bound journals we dragged to the xerox machine are now available from the internet with a few keystrokes on a laptop. Nonetheless, we have chosen to stick with our original format of text alternating with reprinted articles, believing Gutenberg will survive Gates and that there is still great value in having the physical text in your hands.

Choosing articles to reprint has become more difficult with the proliferation of experiments aimed at the most promising measurements. In some cases we have been forced to make an arbitrary selection from competing experiments with comparable results.

We would like to acknowledge again the physicists whose papers we reprint here. We have benefited from the advice of many colleagues for this Second Edition and would like to mention, in particular, Stuart Freedman, Fred Gilman, Dave Jackson, Zoltan Ligeti, Kerstin Tackmann, Frank Tackmann, George Trilling, and Stan Wojcicki.

R. N. C.
G. G.
Berkeley, California, 2008

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Preface to the First Edition

Fifty years of particle physics research has produced an elegant and concise theory of particle interactions at the subnuclear level. This book presents the experimental foundations of that theory. A collection of reprints alone would, perhaps, have been adequate were the audience simply practicing particle physicists, but we wished to make this material accessible to advanced undergraduates, graduate students, and physicists with other fields of specialization. The text that accompanies each selection of reprints is designed to introduce the fundamental concepts pertinent to the articles and to provide the necessary background information. A good undergraduate training in physics is adequate for understanding the material, except perhaps some of the more theoretical material presented in smaller print and some portions of Chapters 6, 7, 8, and 12, which can be skipped by the less advanced reader.

Each of the chapters treats a particular aspect of particle physics, with the topics given basically in historical order. The first chapter summarizes the development of atomic and nuclear physics during the first third of the twentieth century and concludes with the discoveries of the neutron and the positron. The two succeeding chapters present weakly decaying non-strange and strange particles, and the next two the antibaryons and the resonances. Chapters 6 and 7 deal with weak interactions, parity and CP violation. The contemporary picture of elementary particles emerges from deep inelastic lepton scattering in Chapter 8, the discovery of charm and the tau lepton in Chapter 9, quark and gluon jets in Chapter 10, and the discovery of the b-quark in Chapter 11. The synthesis of all this is given in Chapter 12, beginning with neutral current interactions and culminating in the discovery of the W and Z.

A more efficient presentation can be achieved by working in reverse, starting from the standard model of QCD and electroweak interactions and concluding with the hadrons. This, however, leaves the reader with the fundamentally false impression that particle physics is somehow derived from an *a priori* theory. It fails, too, to convey the standard model's real achievement, which is to encompass the enormous wealth of data accumulated over the last fifty years.

Our approach, too, has its limitations. Devoting pages to reprinting articles has forced sacrifices in the written text. The result cannot be considered a complete textbook. The reader should consult some of the additional references listed at the end of each chapter.

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The text by D. H. Perkins provides an excellent supplement. A more fundamental problem is that, quite naturally, we have reprinted (we believe) correct experiments and provided (we hope!) the correct interpretations. However, at any time there are many contending theories and sometimes contradictory experiments. By selecting those experiments that have stood the test of time and ignoring contemporaneous results that were later disproved, this book inevitably presents a smoother view of the subject than would a more historically complete treatment. Despite this distortion, the basic historical outline is clear. In the reprinted papers the reader will see the growth of the field, from modest experiments performed by a few individuals at cosmic-ray laboratories high atop mountains, to monumental undertakings of hundreds of physicists using apparatus weighing thousands of tons to measure millions of particle collisions. The reader will see as well the development of a description of nature at the most fundamental level so far, a description of elegance and economy based on great achievements in experimental physics.

Selecting articles to be reprinted was difficult. The sixty or so experimental papers ultimately selected all played important roles in the history of the field. Many other important articles have not been reprinted, especially when there were two nearly simultaneous discoveries of the same particle or effect. In two instances, for the sake of brevity, we chose to reprint just the first page of an article. By choosing to present usually the first paper on a subject often a later paper that may have been more complete has been neglected. In some cases, through oversight or ignorance we may simply have failed to include a paper that ought to be present. Some papers were not selected simply because they were too long. We extend our apologies to our colleagues whose papers have not been included for any of these reasons. The reprinted papers are referred to in boldface, while other papers are listed in ordinary type. The reprinted papers are supplemented by numerous figures taken from articles that have not been reprinted and which sometimes represent more recent results. Additional references, reviews or textbooks, are listed at the end of each chapter.

Exercises have been provided for the student or assiduous reader. They are of varying difficulty; the most difficult and those requiring more background are marked with an asterisk. In addition to a good standard textbook, the reader will find it helpful to have a copy of the most recent *Review of Particle Properties*, which may be obtained as described at the end of Chapter 2.

G. G. would like to acknowledge 15 years of collaboration in particle physics with Sulamith Goldhaber (1923–1965).

We would like to thank the many particle physicists who allowed us to reproduce their papers, completely or in part, that provide the basis for this book. We are indebted, as well, to our many colleagues who have provided extensive criticism of the written text. These include F. J. Gilman, J. D. Jackson, P. V. Landshoff, V. Lüth, M. Suzuki, and G. H. Trilling. The help of Richard Robinson and Christina F. Dieterle is also acknowledged. Of course, the omissions and inaccuracies are ours alone.

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Berkeley, California, 1988

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