Introduction to Nuclear and Particle Physics

Second Edition

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Introduction to Nuclear and Particle Physics

Second Edition

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INTRODUCTION TO NUCLEAR AND PARTICLE PHYSICS (2nd Edition)

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To
Our Teachers
and
Our Students

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Preface

This book is based on a one-semester course on Nuclear and Particle Physics that we have taught to undergraduate juniors and seniors at the University of Rochester. Naturally, the previous experience and background of our students determined to a large extent the level at which we presented the material. This ranged from a very qualitative and hand-waving exposition to one class that consisted of a mix of about six engineering and math majors, to relatively formal and quantitative developments for classes that were composed of about ten to fifteen well-prepared physics majors. It will not come as a great surprise that, independent of the degree of sophistication of our students, they were invariably fascinated by the subject matter, which provided great wonderment and stimulation to them. In class, we strove to stress the general underlying ideas of nuclear and particle physics, and we hope that in transforming our lecture notes into this more formal text, we have not committed the common sin of sacrificing physical content and beauty for difficulty and rigor.

It is quite remarkable how much has changed since we first wrote this book in 1989. The field of heavy-ion collisions has blossomed, the top quark and the τ neutrino were discovered, a very small direct contribution to CP violation has been confirmed in K^0 decays, large CP violation was found in interactions of neutral B mesons, the Standard Model has gained complete acceptance, and many exciting ideas have been proposed for possibilities for physics beyond the scale of the Standard Model. Furthermore, the confirmation of a finite mass for neutrinos has revealed the first chink in the armor, and a clear need for expansion of the Standard Model. The developments in the related field of cosmology have, if anything, been even more dramatic. We were tempted to include some of these in this second edition of our book, but fearing that this might expand it beyond its current scope

and sensible length, we decided not to pursue that option. Nevertheless, we have updated the original material, clarified several previous discussions, and added problems to help test the understanding of the material.

Apologies

This book is intended primarily for use in a senior undergraduate course, and particularly for students who have had previous contact with quantum mechanics. In fact, more than just slight contact is required in order to appreciate many of the subtleties we have infused into the manuscript. A one-semester course in Quantum Mechanics should be of great help in navigating through the fantastic world of nuclear and particle phenomena. Although, in principle, our book is self-contained, there are parts of several chapters that will be daunting. For example, the sections on Relativistic Variables and Quantum Treatment of Rutherford Scattering in Chapter 1, some of the more formal material in Chapters 10, 11, 13, and 14, and the section on Time Development and Analysis of the $K^0 - \overline{K}^0$ System in Chapter 12, are all especially demanding. Although the treatment of the mass matrix for the kaon system may be considered too advanced, and not essential for the overall development of the material in the book, we believe that the other sections are quite important. (Also, we felt that mathematically advanced students would appreciate some of the more challenging excursions.) Nevertheless, if deemed necessary, the formal concepts in these harder sections can be de-emphasized in favor of their phenomenological content.

Having chosen a somewhat historical development for particle physics, we had difficulty in infusing the quark structure of hadrons early into our logical development. We felt that this early introduction was important for familiarizing students with the systematics of hadrons and their constituents. To achieve this goal, we introduced the properties of quarks in the Problems section of Chapter 9, well before the discussion of their relevance in the Standard Model in Chapter 13. Although this might not be the best approach, it should nevertheless provide students, through problems, with the valuable experience of interpreting hadrons in terms of their quark content, and in reducing the possible confusion and frustration caused by keeping track of the many different hadrons.

Units and Tables of Nuclear and Particle Properties

We use the cgs system of units throughout the text, except that energy, mass, and momentum are specified in terms of eV. This often requires the use of $\hbar c$ to convert from cgs to the mixed system. Whenever possible, we have shown explicitly in the text how such change in units is made. Periodically, when we depart from our normal convention, as we do for the case of magnetic moments, we warn the reader of this change, and again offer examples or problems to ease the transition between different conventions.

We have found that the best source of information on properties of nuclei and particles, as well as on fundamental constants, is the all-inclusive *CRC Handbook of Chemistry and Physics* (CRC Press, Inc.) Because every library has copies of this work, we have not provided such detailed information in our manuscript, and urge students to consult the CRC tables when need arises. We have, nevertheless, included some useful physical constants in an appendix to this book.

Other References

The subjects of nuclear and particle physics share a common heritage. The theoretical origins of the two fields and their reliance on quantum mechanics, as well as the evolution of their experimental techniques, provide much overlap in content. It is therefore sensible to present these two areas of physics, especially at the undergraduate level, in a unified manner. And, in fact, there are several excellent texts that have recently been published, or extensively revised, that provide the kind of combined exposition that we have presented. The books *Subatomic Physics* by Hans Frauenfelder and Ernest Henley (Prentice-Hall, Inc.), *Particles and Nuclei* by B. Povh, et al (Springer-Verlag), and *Nuclear and Particle Physics* by W. S. C. Williams (Oxford University Press) are particularly worthy of noting, because they offer a panoramic view of nuclear and particle physics of the kind that we have attempted to give in our book. We believe that the emphasis in all three of these works is sufficiently different and original to make them all complementary and of value to students learning these two exciting fields of physics.

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