

# Preface

This is the second edition of a book that is an outgrowth from a set of lecture notes developed for a one-semester graduate course on the non-relativistic quantum theory of radiation. One of the authors (SHC) has been teaching this course for the past thirty-five years to engineering students preparing to enter doctoral research in the area of Nuclear Science and Technology (NST) in the Department of Nuclear Science and Engineering at the Massachusetts Institute of Technology. The course, entitled *Interaction of Radiation with Matter*, has been required for all students in NST prior to their taking of the Ph.D. qualifying examination. The aim has been to teach graduate students in engineering the basic principles underlying the interaction of electromagnetic and neutron radiations with atomic and molecular systems. The emphasis is on applications to modern-day materials research.

The primary audience for this book is first and second-year graduate students having a BS degree in science or engineering from a standard four-year university. It is assumed that the student has taken a year of general physics and chemistry, advanced calculus, differential equations, and linear algebra. In addition, it is extremely helpful if the student has experienced a one-semester course in modern physics in which basic quantum theory and introductory nuclear physics are taught. The basic lecture notes developed by SHC were designed for a one-semester course, however, this book reflects a highly expanded presentation of the original material, in terms of both content and exposition, developed by MK. Depending on the choice of topics covered by the instructor, this book could serve as the text for either a one-semester or a two-semester course. In either case, most of the first nine chapters should be covered. A two-semester course allows for the study of extended applications appearing in Chapters 10–13.

The aim of the first four chapters of this book is to rapidly elevate the reader's knowledge of fundamental physics to a more advanced level. The student is introduced to the Lagrangian and Hamiltonian formulations of classical mechanics, important elements of classical electrodynamics (including Maxwell's equations, electromagnetic potentials, and the wave equation), and standard nonrelativistic quantum mechanics based on the Dirac formalism. In addition, the treatment of electrodynamics (Chapter 4) includes substantial material on the theory of classical light scattering.

Chapters 5–7 focus on the quantization of radiation and lattice-displacement fields, time-dependent perturbation theory and transition probabilities, as well as the

equilibrium and time-evolution properties of the density operator in statistical mechanics. Chapter 6 also contains a section on the formulation of the double-differential cross-section for the scattering of photons and thermal neutrons (the latter based on the Fermi pseudo-potential). At this point, the student should be prepared to understand basic aspects of the quantum theory of radiation. Chapters 8 and 9 present the topics of photon emission, absorption, and scattering.

The next three chapters illustrate how the theories learned earlier on can be used to understand a number of useful experimental techniques. Examples are chosen from the areas of nuclear magnetic resonance, photon correlation spectroscopy, and thermal neutron scattering. These choices reflect both the expertise of the authors and the interests of students in the M.I.T. Department of Nuclear Science and Engineering.

The final chapter presents, in a concise way, the modern view of the general relationship between theory and experiment in terms of equilibrium correlation functions.

The authors feel that it is of paramount importance to strike a balance between the amount of information one would like to convey in a course like this and the practical limits set by what a capable student can reasonably learn and digest during a four-month time period. The material in no way constitutes a complete coverage of the quantum theory of radiation interaction with matter. Rather, it is our intent that the material presented in this book be somewhat different from the standard material covered in, for example, an equivalent graduate course offered by a physics department. Our main goal is not to try to be complete in coverage, but instead to select topics that we feel are useful to students learning how to comprehend and analyze important types of laboratory experiments. In this regard, it is our opinion that the relativistic treatment, which is so standard in a course of this nature, can essentially be omitted.

In order to illustrate the principles presented in each chapter, numerous examples are included that have been worked out in detail. It is our opinion that the value of a new textbook is largely determined by the selection of non-trivial examples it provides to the reader. Furthermore, in this new second edition of the text, the most significant change is the addition of fifty-six substantial end-of-chapter problems. These are not just brief exercises requiring only a simple rehashing of the material found in each chapter. Our philosophy, instead, has been to design problems that serve a pedagogical function, challenging the student to extend his or her understanding of the material, and aimed toward deriving some significant results not already developed within the text. In our opinion, this added feature of the new edition greatly enhances the usefulness of the book as a course text.

The other substantive addition to the book is a discussion of high-resolution inelastic x-ray scattering appearing in Chapter 9. The specific application of this technique to investigating the dynamics of low-temperature liquid water is presented in Example 9.3.

Other, more minor, changes for this edition are the following:

- Example 4.3 on the Hamiltonian formulation for the electromagnetic field plus charged particles has been revised and corrected.
- Various equations throughout the text have been corrected.
- Both the end-of-chapter and end-of-book reference lists have been updated.

We would like to take this opportunity to thank the many graduate students who have taken this course over the years. Their comments about the usefulness of the course have provided us with encouragement for completing this project. Many students have commented that the material presented has helped them significantly in their comprehension of the wide range of literature available to them.

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Sow-Hsin Chen  
Michael Kotlarchyk

Cambridge, Massachusetts, USA  
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