

# Chapter 1

## INTRODUCTION

The exchange of energy between a photon or neutron and a material medium is a fundamentally quantum-mechanical phenomenon. For scientists and engineers who need to deal with the application of radiation probes to condensed matter research, learning to calculate experimentally relevant quantities using the principles of quantum mechanics is a skill that is indispensable. This book is intended to meet this need. It is presumed that any prior training or coursework the reader may have in the formal aspects of standard theoretical physics is minimal.

The most relevant quantity in connection with interpreting data derived from modern laboratory experiments involving radiation-matter interactions is the so-called *double-differential scattering cross-section*; this quantity basically gives the probability that a particular radiation-probe exchanges a given amount of energy and momentum with a target material. In order to calculate this cross-section, one first needs to become familiar with the quantum-mechanical concept of a *transition probability per unit time* between two states. Consequently, the most direct route to an understanding of the interaction between photons and neutrons with matter is to develop some of the basic time-dependent quantum-mechanical perturbation theory leading to the calculation of these transition probabilities.

Even though the foundations of quantum mechanics were formulated early in the twentieth century, many aspects of the theory make use of the much older classical concept of conjugate pairs of canonical mechanical variables and the *Hamiltonian function* of a physical system. It is important, therefore, that the reader have some understanding of the formalism of classical mechanics before exploring elements of the quantum theory.

Another branch of classical physics relevant to the interaction of photons with matter is the theory of electromagnetic (EM) fields and waves. For the purpose of our present study, it is essential that the reader also develop a firm grounding in Maxwell's classical theory of EM radiation because, ultimately, the concept of a photon (i.e., the treatment of the EM field as a mechanical entity) depends on being able to quantize the classical field.

In order to make connections to real physical systems, and hence to actual experimental results, one must also learn some of the basic principles of classical and quantum statistical mechanics. This allows one to perform calculations of various

statistical averages of mechanical variables for a system with many degrees of freedom at a specified temperature.

Figure 1.1 is a flowchart mapping the connections between the various topics treated within this book. In Chapters 2–4 we present, in sequence (and in what we feel are sufficient detail), the cornerstone subjects—classical mechanics, quantum mechanics, and classical electrodynamics. Since these subject areas form the basis for all further discussion in the book, they appear as boxes at the top of the flowchart and, in all probability, should not be skipped by the reader. The presentation is designed to be at a sufficiently elementary level, which allows one to read and understand it with only a minimum of guidance provided by the instructor.

The second level of the flowchart includes the subjects of Chapters 5–7, namely, quantization of the field, the calculation of transition probabilities using the time-dependent perturbation theory, and the role of the density operator in the calculation of statistical averages at a given temperature. Essentially, this level represents the most important part of the book. The subject of “linear response theory” also appears at this level in the chart, but a discussion of this topic is postponed until the final chapter. The authors feel that this is appropriate because, by doing so, we are able to present more examples that are applicable to experiments discussed in the later chapters.

The third level consists of a series of practical applications including photon correlation spectroscopy, nuclear magnetic resonance, and thermal neutron scattering. As mentioned in the preface, these topics should be considered optional for a one-semester course, and are indicated so by the use of dashed boxes in the flowchart. Chapters 8 and 9 on first and second-order radiation processes are considered to be applications at the most fundamental level. Hence, these two topics appear in boxes that are not dashed, and should not be skipped in a course of any length.

The examples presented in each chapter have been carefully selected to illustrate the various principles and techniques introduced. The authors feel that the working principles of quantum mechanics, which are based on rather abstract concepts, are best learned through the use of specific illustrative examples. The reader should pay special attention to these examples, since they show how the various principles can be applied in a concrete manner. Sufficient details are supplied so that the reader can follow along without the assistance of an instructor.

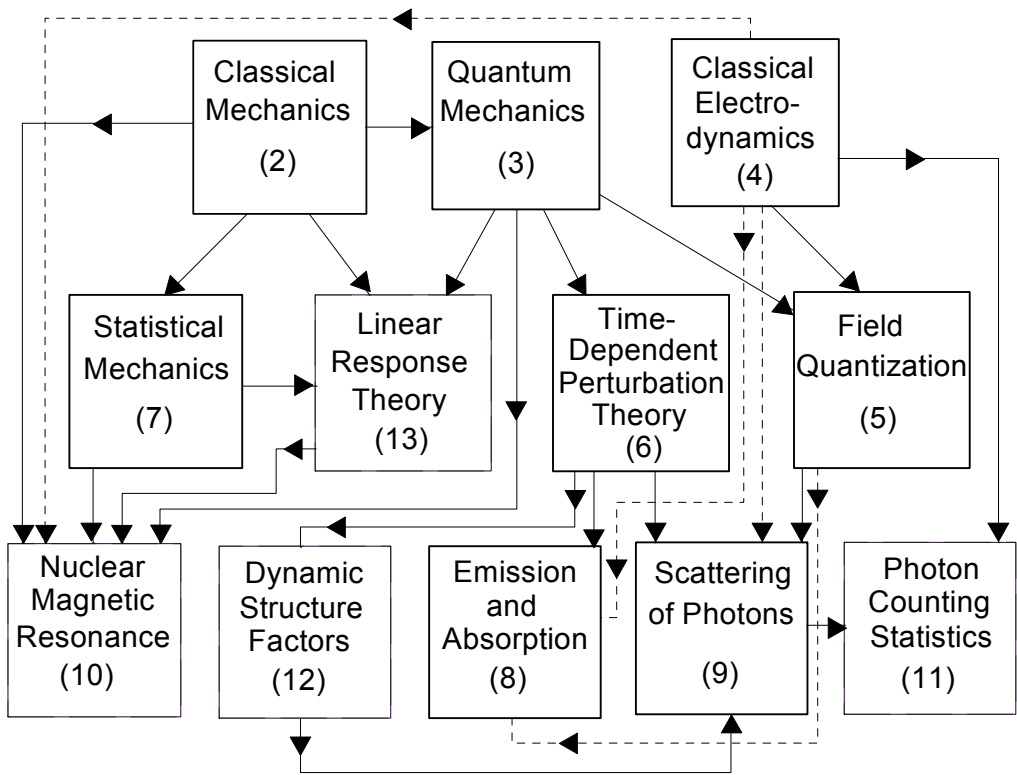


Figure 1.1 Connections between the topics treated in the various chapters of this book. (The numbers in parentheses indicate the relevant chapters.)