

Preface

Quantum optics is one of the main fields in modern physics. As we know, it has been only 30 years since quantum optics became a field of science. Although the birth of the quantum theory of light was due to the Planck's quantum postulate and Einstein's photons hypothesis, using quantum mechanics to study the effects of the interaction between matter (atom, molecular, etc.) and light comprehensively and systematically, as well as to investigate them by experiments, started after the development of the laser at the end of the 1950s. Many new optical effects have been revealed from several different subjects of quantum optics by using lasers. With the development of new experiments, additional optical effects will be revealed which will promote further development and understanding.

The key point of modern quantum optics is to investigate the effects of the interactions between atoms and laser fields. Both atoms and radiation fields display quantum properties in the interaction of one or more atoms with laser fields (single or multimode), which can not be discussed in classical terms. The theory of modern quantum optics demonstrates that one can understand many quantum properties of both the radiation field and the atomic behavior by means of quantum electrodynamics.

The development of quantum optics shows that it is necessary to make a specialized statement on the main contents of quantum optics according to the quantum properties of both atoms and radiation fields in the atom-field coupling system. This book is devoted to this purpose, and is based on our lectures in quantum optics for graduate students, on our research publications over the past few years, and on the latest achievements in the field of quantum optics. We hope that this book will be regarded as a useful book for graduate students, undergraduate students, teachers, as well as scientists who are

interested in quantum optics and theoretical physics.

This book is divided into three parts. The first part is devoted to introducing the elementary theory of the interaction between atoms and light. It includes five chapters which present the basic theory of quantum optics. For better understanding, we have discussed some practical examples. The first part is also as an introduction to the next two parts. In the first chapter of this book, the three pictures of quantum mechanics and the theory of the density operator are outlined. The two-level atom and the optical Bloch equations are discussed in Chapter 2. Chapter 3 deals with the quantum description of the light. We present not the quantization of light but also a specialized discussion on three state functions of the radiation field. Chapter 4 introduces systematically the Dicke model and the Jaynes-Cummings (J-C) model, which are two typical theoretical models. These two models are of wide application. Chapter 5 discusses the quantum theory of a small system coupling to a thermal reservoir. Besides introducing the Langevin equation and the Fokker-Planck equation, we deal with the master equation of the quantum harmonic oscillator. Chapter 5 is about the fundamental theory of the quantum statistical properties of a system in quantum optics. Part II gives a concentrated discussion of the quantum properties of light fields. First we introduce the theory of coherent light in Chapter 6. Then, in Chapter 7 we discuss the theory of squeezed light, which has been recently the subject of extensive investigations. In the following three chapters, we respectively deal with the three important subjects, which are resonance fluorescence, superfluorescence, and optical bistability. The research on these three subjects has almost been completed both theoretically and experimentally. We have tried to keep our presentation simple and fundamental. Chapter 11 describes the effects of the virtual light field on the atom-field coupling system. From the theoretical point of view, it is of interest to investigate the influence of virtual photon processes on the radiation field. Here we give more details according to our recent publications on this subject. Part III deals with the quantum dynamic properties of the atoms interacting with the laser field. First we introduce the periodic collapse-and-revival effects of atomic behavior under the interaction of the laser field in Chapter 12. The squeezing of atomic operators is discussed in Chapter 13. As for the coherent trapping of atomic populations, we give a more detailed discussion in Chapter 14. Chapter 15 is devoted to presenting a theory of a two-atom coupling system under the interaction of the laser field. Here, the effects of the dipole-dipole interaction have been examined in detail. Chapter 16

introduces the autoionization of the atom induced by the laser field. Chapter 17 deals with the atomic motion in the laser field, the deflection and refraction of an atom moving in a standing-wave field and the force acting on the atom driven by the radiation field are discussed. In the last chapter, we concentrate on the recently developing subject of laser cooling. We introduce a quantum theoretical description of the laser cooling, and give some statements on the problems which are related to its applications. Some key references are listed at the end of each chapter, but the lists are not comprehensive.

Although the development of modern quantum optics continues, we believe that the basic theory and the main treatments presented in this book are useful. The presentation of the subject is novel, rigorous and as clear as possible. Readers may learn the simple physical ideas, the advanced theoretical description and the general methods from this book.

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