ATOMS IN INTENSE LASER FIELDS

The development of lasers capable of producing high-intensity pulses has opened a new area in the study of light–matter interactions. The corresponding laser fields are strong enough to compete with the Coulomb forces in controlling the dynamics of atomic systems, and give rise to multiphoton processes. This book presents a unified account of this rapidly developing field of physics.

The first part describes the fundamental phenomena occurring in intense laser–atom interactions and gives the basic theoretical framework to analyze them. The second part contains a detailed discussion of Floquet theory, the numerical integration of the wave equations and approximation methods for the low- and high-frequency regimes. In the third part, the main multiphoton processes are discussed: multiphoton ionization, high harmonic and attosecond pulse generation and laser-assisted electron–atom collisions. Aimed at graduate students in atomic, molecular and optical physics, the book will also interest researchers working on laser interactions with matter.

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Frontmatter
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Felix qui potuit rerum cognoscere causas.
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Preface

The availability of intense laser fields over a wide frequency range, in the form of short pulses of coherent radiation, has opened a new domain in the study of light–matter interactions. The peak intensities of these laser pulses are so high that the corresponding laser fields can compete with the Coulomb forces in controlling the dynamics of atomic systems. Atoms interacting with such intense laser fields are therefore exposed to extreme conditions, and new phenomena occur which are known as multiphoton processes. These phenomena generate in turn new behaviors of bulk matter in strong laser fields, with wide-ranging applications.

The purpose of this book is to give a self-contained and unified presentation of high- intensity laser–atom physics. It is primarily aimed at physicists studying the interaction of laser light with matter at the microscopic level, although it is hoped that any scientist interested in laser–matter interactions will find it useful.

The book is divided into three parts. The first one contains two chapters, in which the basic concepts are presented. In Chapter 1, we give a general overview of the new phenomena discovered by studying atomic multiphoton processes in intense laser fields. In Chapter 2, the theory of laser–atom interactions is expounded, using a semi-classical approach in which the laser field is treated classically, while the atom is described quantum mechanically. The wave equations required to study the dynamics of atoms interacting with laser fields are discussed, starting with the non-relativistic time-dependent Schrödinger equation in the dipole approximation, then moving to the description of non-dipole effects and finally to relativistic wave equations.

The second part, containing five chapters, is devoted to a detailed discussion of the most important theoretical methods used to solve the wave equations given in Chapter 2. We begin, in Chapter 3, by considering perturbation theory, which can only be employed for laser fields having moderate intensities and for non-resonant multiphoton processes. In the next four chapters we discuss non-perturbative methods, which must be used when atoms interact with strong laser fields. In Chapter 4, we review the Floquet theory, in particular the Sturmian-Floquet and *R*-matrix–Floquet methods. Chapter 5 is devoted to the numerical solution of the wave equations. Approximation methods appropriate to investigate the interaction of atoms with low-frequency and high-frequency laser fields are considered in Chapters 6 and 7, respectively. It is remarkable that in these two distinct frequency regimes, simple theoretical considerations provide considerable insight into the physics of intense laser–atom interactions.

In the third part of the book, which contains the final three chapters, the methods discussed in the second part are applied to the analysis of the three most important atomic multiphoton processes in intense laser fields: multiphoton ionization, harmonic generation and laser-assisted electron–atom collisions. Thus, in Chapter 8 we discuss successively multiphoton single and double ionization of atoms. In Chapter 9, after analyzing the emission of harmonics by atoms, we review the generation and characterization of attosecond pulses, and their use in the new field of attophysics. Finally, in Chapter 10, we begin our theoretical analysis of laser-assisted electron–atom collisions by considering the simple case for which the target atom is modeled by a potential. We then turn our attention to collisions with real atoms having an internal structure.

We wish to thank our colleagues and students for numerous helpful discussions and suggestions. One of us (C.J.J.) would like to acknowledge the hospitality of the Max-Planck Institut für Quantenoptik in Garching, where he was the guest of Professor H. Walther and more recently of Professor F. Krausz. We would also like to thank Professor H. Joachain-Bukowinski and Professor N. Vaeck for their help in preparing the diagrams.