

# QUANTUM ELECTRODYNAMICS APPLIED TO ATOMIC AND OPTICAL PHYSICS

## Atom-Photon Interactions: Basic Processes and Applications

Claude Cohen-Tannoudji,  
Jacques Dupont-Roc and  
Gilbert Grynberg

Wiley, New York, 1992. 656 pp.  
\$69.95 hc ISBN 0-471-62556-6

Reviewed by Pierre Meystre

*Atom-Photon Interactions: Basic Processes and Applications* by Claude Cohen-Tannoudji, Jacques Dupont-Roc and Gilbert Grynberg is a continuation of *Photons and Atoms: Introduction to Quantum Electrodynamics* by the same authors, originally published in French in 1987 and published in English by Wiley in 1989. The first volume developed quantum electrodynamics in a way particularly suited to problems in laser spectroscopy and quantum optics, emphasizing the Coulomb gauge and treating the particles non-relativistically. *Atom-Photon Interactions* starts where the first book stopped and applies the same theoretical framework to fundamental processes in atom-field interactions.

For the benefit of the hurried reader, let me state at the onset that this book, like its predecessor, is an unqualified success and a must for any serious student or active researcher in atomic, molecular and optical physics. And like the first volume, it is organized along the lines of *Quantum Mechanics* (Vols. 1-2, Wiley, New York, 1977) by Cohen-Tannoudji, Bernard Diu and Frank Lal  . The main text is divided into six short chapters that contain the core material necessary for a basic understanding of the field. Each chapter is followed by a

number of "complements" that develop in more detail some aspects of the theory, discuss specific examples or treat additional problems. For the teacher, this structure has the advantage of permitting one to tailor a course to a specific audience. There might be a certain element of frustration in doing so, however, as the complements are chosen with such good taste that it might prove difficult to select one over another. Adding to this "difficulty," *Atom-Photon Interactions* concludes with over 100 pages of fully worked out exercises.

One of the major difficulties in writing a text on atom-field interactions is that the subject is so broad that the author must make a number of difficult choices. One of the choices made by these authors is to systematically treat the fields quantum mechanically. The advantage of this approach is that it permits the development of a systematic and logical construct. But this method can sometimes be misleading: Although it is of course true in principle that the electromagnetic field should be described quantum mechanically, it is just as true that a vast majority of problems in atomic, molecular and optical physics do not require such sophistication. A number of these problems become hopelessly complicated when one goes beyond the semiclassical approximation. For instance, the pulse area theorem would most likely not have been discovered in a fully quantized description of pulse propagation. This remark is a warning rather than a criticism: The typical first-year graduate student at a US university does not have the degree of sophistication of a French student at one of the elite "Grandes Ecoles," to whom this book was originally addressed. To expose him or her to *Atom-Photon Interactions* in a first quantum optics or optical physics course would be, in my opinion, a mistake and a disservice. This text will be most useful to students who have already taken a more elemen-

tary course.

Let me now turn to the specifics of the book. The first two chapters cover a perturbative approach to atom-field interactions. Chapter I reviews the concept of probability amplitude and introduces a diagrammatic approach used throughout the book. Chapter II begins by introducing single-photon emission and absorption and scattering. It then turns to a perturbative discussion of multiphoton processes, discusses radiative corrections and concludes with a section on interactions by photon exchanges. Both chapters are quite short. The presentation is descriptive and uncluttered by algebra, physical insight being definitely preferred. Technical details and specific examples are relegated to complements. I particularly liked complement  $C_1$ , which discusses the coupling of a discrete level to a continuum and Fano profiles, and complement  $A_{II}$ , on photodetection signals and correlation functions.

The last four chapters concentrate on nonperturbative methods. Chapter III discusses the resolvent method and shows how it can be used to partially resum perturbation series. I especially enjoyed the discussion of the transition between the weak coupling limit, characterized by the exponential decay of a discrete level coupled to a continuum, and the strong coupling regime characterized by Rabi oscillations.

Chapter IV, on reservoir theory, concentrates mostly on the master equation. The examples considered in detail (a two-level atom coupled to the radiation field and the damped harmonic oscillator) are quite standard. To my knowledge the discussion of the evolution of the atomic velocity distribution due to momentum exchange between the atom and the field appears for the first time in a textbook.

I was somewhat surprised at the relatively small place given to the quantum-noise-operator approach, which is relegated to a complement.

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As it is elegantly used in chapter V to compute the Mollow resonance-fluorescence triplet, one might have expected more emphasis on both this method and on the quantum regression hypothesis.

The last chapter discusses the dressed-atom formalism, an approach made famous by the French school that offers unique insight into many aspects of light-matter interactions. It is sometimes argued that relaxation phenomena are difficult to handle with this formalism and that a bare-atom description is preferable in such cases. The dressed-states basis master equation, also discussed in this chapter, shows that this need not be the case, and the recent success of this approach in the theory of Sisyphus cooling speaks for itself.

*Atom-Photon Interactions* is an essential addition to the personal bookshelf of any serious student or researcher in the field. My hope is that we will soon be treated to a follow-up volume of the same caliber, one that concentrates perhaps on atomic motion in laser light, a field in which the authors have made a number of trailblazing contributions.

## Matter and Methods at Low Temperatures

Frank Pobell

Springer-Verlag, New York,  
1992. 319 pp. \$79.00 hc  
ISBN 0-387-53751-1

If we follow the introduction to Frank Pobell's new book, then the area of science we call low-temperature physics is about 150 years old, starting with Faraday's liquefaction of a gas. Temperatures achieved in the laboratory have plunged logarithmically with time. The quest for lower temperatures has led to the discovery of new quantum states in liquid and solid materials, with superconductivity and superfluidity being the most notable examples. There is no doubt that as temperatures are reduced to even lower decades, new physical phenomena will be found.

Pobell's work is the latest in a growing number of books treating this topic. I have been asked by my colleagues if they should add this one to their libraries. The answer is yes, for the following reasons.

Pobell's book addresses the properties of materials and the methods of low-temperature physics between 10 K and 12  $\mu$ K, this lowest temperature being a record held by the author and his research group at Bayreuth in Germany. Topics covered in seven chapters include cryoliquids and oth-