Preface

This book is volume I in a two-piece study of dispersion forces as described within the context of macroscopic quantum electrodynamics (QED) in dispersing and absorbing media. Its purpose is threefold: To provide insights and intuitions into macroscopic QED and dispersion forces; to enable the reader to perform his/her own calculations of such forces; and to serve as a reference for dispersion forces in concrete geometries and scenarios. For these purposes, calculations and derivations are laid out in detail and broken down into small steps. Common tricks and approximations are explicitly shown. The results are linked to the pioneering historic works as well as recent research in the field and made plausible by simple physical models.

The book is mainly aimed at three groups of readers. First, it shall provide graduate and postgraduate students with a practical introduction to the field of dispersion forces. While mainly intended for self-study, it can also serve as the basis for a graduate lecture course where many of the worked examples can be used as exercises. Second, this book shall provide researchers from various fields with an overview on macroscopic QED and dispersion forces, providing them with both qualitative results and the theoretical tools for quantitative calculations. Finally, it should serve experimentalists as a means to numerically evaluate dispersion forces and potentials for relevant practical scenarios.

While the basics of macroscopic QED as well as dispersion forces between ground-state objects have been covered in detail in Vol. I, this Vol. II addresses more advanced topics most of which are subject to the current research. These include relations between dispersion forces, Casimir–Polder (CP) potentials of excited or moving atoms, and the impact of finite temperature. To ensure that Vol. II can be read independently, the material of Vol. I is briefly reviewed in the beginning. Occasionally, references to the more detailed material in Vol. I are given.

The content of this volume is laid out as follows. Chapter 1 contains a review of the main results of Vol. I. It summarizes the formalism of macroscopic QED as well as the calculations of ground-state dispersion potentials. For CP potentials, these calculations will be generalized and presented in more detail in Chap. 4.

Readers of Vol. I can skip this Chap. 1, although it might give a new, more condensed, and unified view on macroscopic QED and ground-state dispersion forces.

In Vol. I, ground-state dispersion forces have been calculated explicitly for highly symmetric geometries. In Chap. 2 of this volume, we develop methods for approximating CP potentials for bodies of arbitrary shapes. Based on a Born expansion, it is shown that the potential can be alternatively obtained from a series of volume integrals over the bodies or by summing over appropriately chosen body parts. These approximations are illustrated for the examples of a ring and an inhomogeneous half space.

In Chap. 3, we compare Casimir forces between bodies, CP forces between atoms and bodies, and van der Waals (vdW) forces between atoms and draw connections between them. Reviewing asymptotic power laws for various geometries in the long and short-distance limits, we show that they are special cases of the general scaling behavior of dispersion forces. Using the methods of Chap. 2, we show that forces on bodies are simple sums over the forces on the atoms contained therein in the dilute-gas limit. For more dense bodies, many-atom contributions need to be taken into account. This is explicitly demonstrated for the CP potential, leading to general expressions for many-atom vdW potentials.

The CP potential of a ground-state atom is studied in detail in Chap. 4 of Vol. I, as reviewed in Chap. 1 of this volume. These results are extended to excited atoms in Chap. 4, where we derive the CP potential of an excited atom by means of perturbation theory. The alternative minimal and multipolar coupling schemes are seen to lead to equivalent results. Invoking the Green's tensor given in App. A, we discuss the examples of an excited atom in front of a perfectly conducting plate or a magnetodielectric half space. The more advanced scenario of an atom in front of a meta-material superlens is also considered.

The results are further generalized in Chap. 5 where the dynamics of the excited-state force is considered. As shown, the time-dependent force can be found from the quantum averaged Lorentz force. It is governed by the spontaneous decay of the initially excited atom. As illustrated by the example of an atom near a plate, the strength of the excited state force sensitively depends on the environment-induced shifts and broadenings of the atomic transition frequencies.

Chapter 6 focusses of the resonant force on an excited atom under strong-coupling conditions in cavity QED. Using the Jaynes–Cummings model together with a dressed-state approach, we generalize the approach of Chap. 4 beyond perturbation theory. The CP potential follows from the eigenenergies of the strongly coupled atom–field system. In close similarity to Chap. 5, we also address the dynamics of the strong-coupling force.

The impact of finite temperature on the CP force is addressed in Chap. 7. We first use a perturbative approach to calculate the CP potential of a ground-state or excited atom in a finite-temperature environment. Using the examples of an atom in front of a perfectly conducting plate or a metal half space, we illustrate the intertwined dependence of the thermal CP potential on distance, temperature, and atomic transition frequencies. Following the Lorentz-force approach of Chap. 5, we then consider the dynamics of the force for non-equilibrium scenarios.

The final Chap. 8 is devoted to the effect of motion on the CP force. Using the Lorentz-force approach, the leading non-relativistic velocity dependence of the force is derived. The results are applied to the quantum friction on an atom moving parallel to a plate. The differences of quantum friction for excited versus ground-state atoms near metal or dielectric plates are discussed.

Two appendices provide technical background and reference material. Appendix A collects information about the classical Green's tensor for the electromagnetic field. In addition to reviewing the general properties and specific examples contained in App. B of volume I, the scaling behavior and Born expansion of the Green's tensor are given. Appendix B is a brief review of atomic physics as needed for the examples studied in Chaps. 7 and 8.

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