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 to 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. Firstly, 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. The mathematics of the classical Green's tensor presented in App. B could by itself form a module of a lecture on mathematical methods. Secondly, 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. Thirdly, it should serve experimentalists as a means to numerically evaluate dispersion forces and potentials for relevant practical scenarios.

This Vol. I contains the basics of macroscopic QED and a discussion of dispersion forces between ground-state objects. More advanced topics such as relations between dispersion forces, Casimir–Polder (CP) potentials of excited or moving atoms and the impact of finite temperature are covered in Vol. II. The two volumes can be read independently of one another. Occasionally, cross-references to material in Vol. II are given.

The content of Vol. I is laid out as follows: Chap. 1 provides a self-contained introduction to dispersion forces, which can be read independently of the remainder of this book. After giving an intuitive approach to the phenomenon, we introduce definitions and terminology as used in the literature and point out the relevance of dispersion forces to relevant fields of science. The main part of the chapter gives an overview over the main approaches to calculating and measuring dispersion forces. It also provides a guide to the results found by these methods. Extensive tables provide an overview over the geometries and effects studied to date.

Chapter 2 contains an outline of macroscopic QED and thus provides the essential background required in order to understand the further parts of the book. Macroscopic QED is motivated and introduced as founded on both classical macroscopic electrodynamics in media and quantum electrodynamics in free space. The minimal or multipolar coupling of atoms or molecules to the quantised electromagnetic field is introduced as a basis for Chaps. 4 and 5.

Using macroscopic QED as a basis, Casimir forces on ground-state bodies at zero temperature are studied in Chap. 3. General expressions for the force are derived on the basis of the equivalent Lorentz force and stress tensor approaches. The results are combined with the Green's tensor derived in App. B to calculate the Casimir force between two plates, making contact to the famous results by Casimir and Lifshitz.

Chapter 4 is devoted to CP forces between a single ground-state atom and bodies at zero temperature. Following the approach of Casimir and Polder, the force is derived from the perturbative energy shift of the atom–field system. Using the alternative minimal and multipolar coupling schemes, equivalent general expressions are obtained for the force on an electric atom. The multipolar results are generalised to magnetic and chiral atoms or molecules. They are then used in conjunction with the Green's tensors given in App. B to derive the CP potential of an atom in various planar geometries, such as half spaces, plates and planar cavities. We recover the famous results of Lennard-Jones, Casimir and Polder. As a second example, we study the CP potential of an atom next to a sphere.

Chapter 5 discusses van der Waals (vdW) forces between two ground-state atoms at zero temperature. General expressions for the vdW potential are again derived using perturbation theory, where Feynman diagrams are used to keep track of the various contributions. Results for purely electric atoms are generalised to atoms with magnetic properties. The relevant Green's tensor from App. B is used to obtain the vdW potential of two ground-state atoms in free space. We recover the historic results of London, Casimir and Polder. It is then shown how the interatomic interaction is modified by the presence of a nearby body such as a plate or sphere.

Two appendices provide technical background material. Appendix A contains derivations of field commutators within the context of macroscopic QED. They are required to verify the consistency of the theory in Chap. 2 and to derive the equations of motion for both charged particles and electromagnetic fields. Appendix B is a self-contained discussion of the classical Green's tensor of the electromagnetic field which plays a central role in macroscopic QED. General properties of the Green's tensor are presented; and it is shown how boundary conditions are used to calculate the Green's tensor for specific planar or spherical geometries. The results are used throughout the book to study dispersion forces.

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