Preface

All media are surrounded by a fluctuating electromagnetic field due to the thermal and quantum fluctuations of the current densities inside them. Close to the surface, this fluctuating electromagnetic field is strongly enhanced due to the existence of evanescent electromagnetic waves. This enhancement is especially large when, on the surface, there are surface modes such as surface plasmons, surface polaritons, or the vibrational modes of adsorbates. In the presence of the surface modes, thermal radiation can exhibit spatial and temporal coherence.

In last few years, significant progress was achieved in the study of electromagnetic fluctuations at the nanoscale. This is connected with the development of new experimental methods, which made it possible to probe these fluctuations at the nanoscale, where fluctuations are much stronger than at larger length scales. Thus, the measurements of Casimir–van der Waals forces were recently carried out with unprecedented accuracy. These measurements agree with the theory of van der Waals forces up to very large distances, where retardation effects become essential, and where the interaction is determined by thermal fluctuations rather than quantum fluctuations.

In recent years, considerable attention has been devoted to the studies of electromagnetic fluctuations for non-equilibrium systems. It was theoretically predicted and experimentally confirmed that the radiative heat flux between two bodies with different temperature in the near-field region is many orders of magnitude larger than determined by the classical Stefan–Boltzmann law. Even more remarkable is the fact that, for two bodies in relative motion, the electromagnetic fluctuations result in a friction force, which is non-zero even in the absence of direct contact between the bodies, i.e. isolated from each other by a vacuum gap. This type of friction was measured between the electrons in quantum wells, and between ions in narrow channels filled with liquid. We expect even larger such non-contact effects as the technology for tailoring atomic and nanoscale materials improves.

In this monograph, a general theory of electromagnetic fluctuations is presented. Both equilibrium and non-equilibrium electromagnetic fluctuations are examined. The theory is applied for calculation of the thermal radiation, interaction forces, and the radiative heat transfer between bodies in relative motion.

This monograph is organized as follows. A brief survey of the Casimir forces, radiative heat transfer, and non-contact friction is given in the introduction (Chap. 1). Chapter 2 presents an introduction to the theory of surface electromagnetic waves. As shown in the subsequent sections, these surface waves play a key role in the emissive and reflective surface properties. A brief description of the theory of the fluctuating electromagnetic field is given in Chap. 3. Here, electromagnetic fluctuations in thermodynamic equilibrium, and for non-equilibrium systems, are examined. The general theory of the fluctuating electromagnetic field is applied to the thermal emission by plane sources (Chap. 4), Casimir interaction (Chap. 5), radiative heat transfer (Chap. 6) and Casimir friction for the plate–plate (Chap. 7) and particle–plate (Chap. 8) configurations. Special attention is paid to the possible mechanisms of enhancement of the radiative heat transfer and Casimir friction. The theory of the frictional drag in nanostructures, induced by the fluctuating electromagnetic field, is examined in Chap. 9. The friction drag, which appears in low-dimensional electronic systems, and in narrow channels with polar liquid, is studied. Special attention is devoted to Casimir physics for graphene (see Chap. 10), a material that has been proposed for the micro- and nanoelectromechanical systems of future generations. Quantum Vavilov–Cherenkov radiation, associated with the uniform motion of a neutral object is considered in Chap. 11. The phononic heat transfer for planar and rough interfaces is considered in Chaps. 12 and 13, respectively. The theory of electrostatic friction is presented in Chap. 14. This mechanism of friction is connected with the electromagnetic field, created outside the moving body by static electric charges, which are always present on the surface due to it heterogeneity, or due to an applied voltage. Enhancement of the electrostatic friction due to the vibrational modes of adsorbates and 2D electron structures is analyzed. The non-contact friction theory is compared with experimental measurements. The friction resulting from the emission of acoustic phonons, and due to the internal friction, is studied in the Chap. 15.

The details of some calculations, which are not of direct physical interest, are given in the appendices.

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