Electric discharges with a relatively low contribution of power and weak current are usually referred to as glow discharges or glows. The glows have different forms, are characterized by the frequency of the supply voltage, the size and the shape of the electrodes and discharge volumes, and the composition and pressure of gas fillings. The golden age of physics of gas discharges has been associated with the names of J J Thomson, Townsend, Langmuir, von Engel, Steinbeck, Druyvesteyn and others and has been marked by such fundamental achievements as discoveries of electrons and x-rays, development of spectral analysis, etc. Those achievements have established the foundation of modern physics. At present, in order to study the fundamental laws of nature, other methods are used. But the applied importance of processes in gas discharges has immeasurably increased. In this regard, there is an important need to be able to create gas-discharge devices with predefined properties and parameters. To do that, we need to have a deep understanding of the physical processes in the discharges.

Up to now considerable progress has been made in understanding the kinetics of discharges. It is now possible to obtain characteristics of the simplest types of discharges from ‘first principles’. The most clearly kinetic phenomena have manifested in weak-current discharges of low and medium pressure. In such discharges, plasma is very far from thermodynamical equilibrium. The external energy in the discharge mainly goes primarily to electrons. Transferring it from electrons to heavy plasma particles is usually, for some reason, difficult and the removal of energy from heavy particles, especially at low pressures, occurs relatively quickly. As a result, in the discharges, the most non-equilibrium part is the electron component, so for its description the kinetic analysis is really necessary. Logical development of this area of physics inevitably leads to the fact that the description of the discharges becomes the kinetic one.

To understand physics and technology at the modern level, it is necessary to be well versed in this field. Recently, work in this direction has been developing
intensively, and although, in our opinion, only the first steps have been taken, a self-consistent kinetic description of the simplest glow discharges has became possible. However, this information has been scattered across numerous articles and reviews.

The purpose of this book is to illustrate the basic physical mechanisms and principles of the glows, enabling readers to study the modern literature and successfully participate in scientific and technical progress. There are a number of excellent textbooks and monographs on the physics and phenomenological description of gas discharges of various types. Among them are the book by Lieberman and Lichtenberg [1], a series of books by Raizer and co-workers [2–4], Biberman’s book [5], the books of Chen [6], Smirnov [7] and others. We can also mention a recent review [8]. The nature of the present book (as well as books [9, 10], which are published in Russian only) and its main difference from the above publications are, first of all, in its deeper kinetic level of description of the glow discharges. That allows us to describe glows in a single and much more precise manner of the basic properties of the discharges. All of the development of modern physics of discharges contributes to the deepening and development of a more accurate primarily kinetic description. This gives the possibility to adequately describe these objects quantitatively, which is extremely important for numerous technical applications. Reading this book assumes acquaintance with one of the above monographs, as well as some knowledge of charge particle kinetics in gas-discharge plasmas (for example, book [11] and reviews about non-local electron kinetics [12–14]) and mathematics at the level of a standard university course.

This book is structured as follows. The second chapter of the book discusses ionization in the electric fields. The electrons and ions may be generated in the gas volume by ionization, whose intensity strongly depends on the field. In the weak field there is no, or not enough, generation of charged particles to have self-sustained discharge. Townsend established experimentally the ionization relationships and introduced the key ionization characteristic (the first Townsend coefficient). The chapter concludes with a brief discussion of the differences of ionization in low and high electric fields, including the influence of runaway electrons. The ionization in the strong field may be essentially non-local and the concept of the first Townsend coefficient may not be applicable.

The third chapter is devoted to the description of the microwave breakdown, which is a more simple case with respect to the dc breakdown. In this case diffusion of electrons to the volume walls may be important. The breakdown behavior may depend on the wave frequency \( \omega \). Application to the discharge gap of even a small dc electric field may also change the breakdown properties.

In chapter 4 the description of the dc breakdown is provided, the second Townsend coefficient is introduced and the Paschen curve is discussed. It is demonstrated that the breakdown on the right-hand side of the Paschen curve is in good agreement with the local theory. At the same time, the left-hand side of the Paschen curve can occur due to essentially non-local processes, since in this case the breakdown occurs in strong electric fields. This chapter discusses the relationship and the difference between the breakdown of Townsend [15], formulated for the
breakdown of a direct current, and the Brown’s criterion [16] for the breakdown in microwave fields.

The general structure of a discharge between cold electrodes is described in chapter 5. Most discharge laboratory experiments have been conducted in long cylindrical tubes. In this section the $IV$-traces and axial structures are discussed. A typical discharge has a number of areas like the Faraday dark space (FDS), negative glow (NG), and positive column (PC). Some of them may be absent (like PC).

In chapter 6 we consider the Townsend discharge, in which the effect of the space charge is negligible, and conditions for the applicability of the traditional hydrodynamic approximation are discussed. It turns out that for the discharge on the right branch of the Paschen curve we apply a local approach in which ionization is approximated using the first Townsend coefficient $\alpha$, which depends on the local value of the electric field, while the effective coefficient for ion–electron emission $\gamma_{\text{eff}}$ is substantially reduced due to kinetic effects. As the discharge current rises, the electric field distortion by the space charge begins to play a role and the Townsend discharge on the right branch of the Paschen curve becomes unstable. The development of this instability leads to the establishment of a mode of normal current density. In this mode, ionization becomes non-local. The situation on the left branch of the Paschen curve is different. The field is rather high and at mean free path an electron acquires considerable energy. As a result, the phenomenon of runaway electrons begins to play a substantial role. For its description a sequential kinetic analysis is required [17].

Chapter 7 is devoted to a description of a short (without positive column) dc discharge. Since the positive column is not an obligatory discharge structure, this allows us to consider only the most significant discharge phenomena (without which the discharge cannot exist), that is, those phenomena that occur at the electrodes. The cathode region of the discharge is essentially non-local. Attempts to describe it in the hydrodynamic approximation are not allowed to simulate all phenomena occurring in this region. Therefore, its description must be essentially kinetic. The anode region still does not have a comprehensive and detailed explanation.

The positive column of a glow dc discharge is the most studied plasma object. Its kinetic analysis is described in chapter 8. It turns out that the traditional hydrodynamic approach cannot adequately describe many important characteristics of even this simplest object; only kinetic analysis allows us to explain these characteristics consistently. At low and medium pressure, the EDF in the PC is non-local, i.e. it does not factorize as a product of the electron density and a function of the velocity, the form of which is determined by the local value of the axial electric field. In the limiting case of low pressures there is a complete non-locality of the EDF and it depends only on the total energy $\varepsilon$ (the sum of the kinetic energy $w$ and the potential energy in the electric field $-e\varphi$).

Sections 4.3, 7.3, 7.4 and 7.5 have been written by V Demidov and A Kudryavtsev. The rest of the text has been written by A Kudryavtsev and C Yuan. Some important issues connected to glows have not been considered in this book. These are detailed electron kinetics, striations, discharges with hollow cathodes and some others which the authors intend to discuss in separate publications.
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