subject is called fluid dynamics. Here, information must be supplied from external considerations or experiment for the transport coefficients: the viscosity \( \eta \), the thermal conductivity \( \lambda \), the diffusion coefficients \( D \), and for conducting fluids, the electrical conductivity \( \sigma \). There are special branches of fluid dynamics, depending on whether the fluid is assumed inviscid or not, and whether the fluid is assumed incompressible or not. In the description of compressible flow, thermodynamics and fluid dynamics are brought together.

Statistical mechanics is concerned with the same kinds of systems as is thermodynamics, but from a microscopic viewpoint. Here, the fundamental quantity is the partition function \( Z \), from which may be derived the property relations such as the equation of state, the dependence of specific heats on fluid state, etc. The inputs necessary for calculating the partition function are the energy levels \( \epsilon_k \) and corresponding degeneracies \( g_k \) for the particles constituting the system. These quantities may be viewed as coming either from experiment or from the theory of atomic structure, or both.

Kinetic theory is concerned with fluids in motion from a microscopic point of view, or more generally, with fluids which may be out of equilibrium. At an elementary level the fundamental quantity here is the mean free path \( l \), but more properly, it is the distribution function \( f(\mathbf{c}) \) of the particle velocities \( \mathbf{c} \). Knowledge of the velocity distribution function leads directly to the transport coefficients as well as to the fluid velocity. The inputs for calculating \( f(\mathbf{c}) \) are the cross sections \( Q \) which describe the probable outcomes of particle collisions. These quantities may be viewed as coming either from experiment or from the theory of atomic processes, or both.

3. TOPICS TO BE COVERED

It would appear that the microscopic approach permits the development of a fluid theory with less dependence on experimental information. This is correct in principle, but the price one pays is to obtain a theory restricted to rather simple kinds of fluid systems. For example, the microscopic theory for liquids is extremely involved, and there are very few important practical results, but a liquid presents no particular difficulty when viewed macroscopically. On the other hand microscopic theory generally leads to a deeper understanding and, more pragmatically, provides the basis for a description of nonequilibrium processes. Indeed, for rarefied gases only the microscopic approach is appropriate. In this book, we shall adopt primarily the microscopic approach. A strictly macroscopic approach to conducting fluids is also possible, but the resulting equations are restricted for the most part to quasi-equilibrium systems.

Our objective in Chapter II is to provide an introduction to the main
microscopic concepts that enter into a description of partially ionized gases and to indicate how the macroscopic properties of gases may be calculated from a knowledge of the microscopic processes. At the same time, the material developed in this chapter should provide the reader with many of the tools necessary for making the kinds of approximate estimates often required by workers in this field. The concept of a cross section, which provides a quantitative measure for the description of microscopic processes, plays a central role in the discussion of this chapter.

Many of the topics introduced in Chapter II are developed more fully and with greater precision in subsequent chapters. Introductory aspects of the theory concerned with the calculation of the cross sections for collisional and radiative processes are discussed, respectively, in Chapters V and VI. The calculation of transport coefficients, which is discussed in Chapter II on the basis of mean-free-path theory, is treated more rigorously in Chapter VIII on the basis of kinetic theory. Microscopic aspects of ionized gases related to the presence of a field of magnetic induction are considered in the first part of Chapter IV.

One of the most important characteristics of a large, electrically neutral collection of charged particles is the tendency for the particles to distribute themselves so as to achieve local electrical neutrality. Partially ionized gases having this property are referred to as plasmas. In Chapter III, we shall show that this tendency towards electrical neutrality occurs in regions whose extent exceeds a characteristic length called the Debye length. A related property is the plasma frequency. Immediately adjacent to solid surfaces, in regions called sheaths, plasmas are usually electrically non-neutral. These concepts are illustrated in Chapter III by a discussion of electrostatic probes and of the propagation of microwaves through plasmas.

Chapter IV is concerned with the motion of an electrically conducting gas in the presence of electric and magnetic fields. We begin with a discussion of the trajectories of a single charged particle in simple configurations of applied electric and magnetic fields. It is shown that on a macroscopic level these idealized trajectories, when combined with the effects of collisions, underlie the phenomena of the Hall effect and ion slip. An equation relating the current density in a gas to the "driving forces" acting on the charged particles, called a generalized Ohm's law, is derived first in Sec. 3 under simplifying assumptions, and then in Sec. 8 for more general conditions.

In Secs. 4, 5, and 6 of Chapter IV we discuss how the continuum conservation equations for nonconducting fluids may be extended to provide a description of the motion of electrically conducting fluids. The discussion of Hartmann flow in Sec. 7 provides an example of the application of the dynamical equations. The electrical equations are employed in Sec. 9 in conjunction with a discussion of MHD power generation. Section 10 provides
an illustration of the application of these equations to describe an important instability that can occur in two-temperature plasmas.

Chapter V presents an introduction to some of the theoretical elements involved in the calculation of collision cross sections. Classical results for elastic scattering are derived based on Newtonian mechanics, and the domain of validity of these results is examined in light of the Heisenberg uncertainty principle. Examples of quasiclassical calculations for nonelastic processes are discussed.

Rigorous calculations relating to radiative processes (as well as to nonelastic collision processes) must be based on quantum theory. However, for many of the main radiative processes quasiclassical calculations can be made which illuminate the physics and at the same time lead to results that are remarkably similar to those obtained with quantum theory. We begin in Chapter VI by showing how radiation, on the basis of classical theory as set forth by Maxwell's equations, originates from accelerated charges. This result is then used to obtain descriptions of the radiation emitted from atoms in free-free, free-bound, and bound-bound transitions.

Chapters VII and VIII discuss the formal kinetic theory of partially ionized plasmas. Chapter VII provides the formulation of the basic equations which are used in Chapter VIII to calculate plasma transport properties. Chapter VII proceeds from the Boltzmann equation, which is then modified to account for the simplifications of the collision terms that are possible as a result of the relatively small mass of the electron and the small deflections which are typical of charged-particle collisions. In Chapter VIII the theory of transport properties of weakly ionized, partially ionized, and fully ionized plasmas is discussed. Results for partially ionized plasmas based on the rigorous Chapman-Enskog expansion are compared with those obtained by approximate mixture rules, and recommendations are made for practical calculations.

Chapter IX deals with problems of ionizational nonequilibrium. The rate equations for the population densities of bound and free electrons are used to describe departures from the Saha equation in steady-state and dynamic situations. Examples of flows with ionizational nonequilibrium are discussed.

Each chapter in this book can be followed, in large measure, without having to read completely the material contained in preceding chapters. For this reason a high degree of flexibility exists in selecting material to be covered and the order in which topics are to be covered. The background material that we would suggest be covered in conjunction with each chapter is as follows:

For Chapter III: Chapter II, Secs. 3, 5 to 8, 13

For Chapter IV: Chapter II, Secs. 3, 5 to 8, 12, 3
3. For Chapter V: Chapter II, Secs. 2 to 4, 8; Chapter III, Secs. 1 to 4
4. For Chapter VI: Chapter II, Secs. 2 to 6, 9; Chapter IV, Secs. 1 to 4
5. For Chapter VII: Chapter II, Secs. 1 to 8; Chapter V, Sec. 5
6. For Chapter VIII: Chapter VII
7. For Chapter IX: Chapter II

At Stanford, most of the contents of the book are covered in about four quarters of work. The first quarter usually focuses on the material in Chapters II and III, and on part of either Chapter IV or V. A second quarter begins with the material in Chapter IV and then goes on to discuss other topics in magnetofluidmechanics, such as boundary layers, which are not covered in this book. A third quarter, whose emphasis is on the physics of partially ionized gases, begins with Chapter VI and then proceeds to a discussion of topics in quantum mechanics. A fourth quarter, concerned with kinetic theory, covers the material in Chapters VII, VIII, and IX. The first quarter is the only prerequisite for any of the other three quarters.

4. UNITS

Throughout this book the rationalized MKS system is used for equations written in terms of symbols. In this system the basic units are the meter (m), kilogram (kg), second (sec), and coulomb (C). Secondary units can be expressed in terms of these quantities as follows:

\[
\begin{align*}
1 \text{ newton} & = 1 \text{ kg m sec}^{-2} (= 10^5 \text{ dyn}) \\
1 \text{ joule} & = 1 \text{ W sec} = 1 \text{ kg m}^2 \text{ sec}^{-2} (= 10^7 \text{ erg}) \\
1 \text{ ampere} & = 1 \text{ C sec}^{-1} \\
1 \text{ volt} & = 1 \text{ kg m}^2 \text{ sec}^{-2} \text{ C}^{-1} \\
1 \text{ tesla} & = 1 \text{ kg sec}^{-1} \text{ C}^{-1} (= 10^4 \text{ G}) \\
1 \text{ farad} \text{ m}^{-1} & = 1 \text{ sec}^{2} \text{ C}^{2} \text{ kg}^{-1} \text{ m}^{-3} \\
1 \text{ henry} \text{ m}^{-1} & = 1 \text{ kg m C}^{-2}
\end{align*}
\]

Temperature is given in degrees Kelvin. Numerical results are frequently expressed in conventional or more convenient units as, for example, electron density in cm\(^{-3}\).

5. EQUATION NUMBERING AND OTHER CONVENTIONS

The chapters in this book are indicated by Roman numerals. Each chapter is divided into sections that are identified by Arabic numerals. Unless otherwise qualified, a reference to a section number is to a section in the same chapter. Reference to a section in another chapter is usually indicated by the use of a Roman numeral prefix. Thus, for example, the appearance in Chapter V of a reference to “Sec. 4” would mean section 4 in Chapter V,