

# Preface

This is the second in a series of four volumes, all written at an elementary calculus level. The complete course covers the most important areas of classical physics, such as mechanics, thermodynamics, statistical mechanics, electromagnetism, waves and optics. This second volume deals with fluid mechanics, thermodynamics and statistical mechanics.

The laws of Physics, and, more generally, of Nature, are written in the language of mathematics. The reader is assumed to have previous knowledge of the basic concepts of calculus: vectors, functions, limits and the derivative and integration operations.

Physics is an experimental science, meaning that it is based on the experimental method, which was developed by Galileo Galilei in the seventeenth century. He taught us, in particular, that to try to understand a phenomenon, one must simplify the relevant working conditions as thoroughly as possible, understanding which aspects are secondary and eliminating them as far as possible. The understanding process is not immediate, but rather, it proceeds by trial and error, through a series of experiments, which might lead, with a bit of fortune and a lot of thinking, to the discovery of the governing laws. Induction process of the laws of physics goes back from the observed effects to their causes, and, as such, cannot be purely logical. Once a physical law is found, it is necessary to consider all its possible consequences. This is now a deductive process, which is logical and similar to the mathematical one. Each of the consequences, the predictions, of the law must then be experimentally verified. If only one prediction is found to be false by the experiment, even if thousands of others have been found to be true, it is enough to prove that the law is false or, better yet, to show the limits of its validity. This implies that we can never be completely sure that a law is true; indeed, the number of its possible predictions is unlimited, and in any historical moment, a number of them may be uncontrolled. However, this is the price we must pay in choosing the experimental method, which has allowed humankind to advance much further in the last four centuries than in all the preceding millennia.

Thermodynamics and statistical mechanics are amongst the great intellectual constructions of Physics. Their laws are well established as well as the limits of their validity. Consequently, it can be exposed in an axiomatic way, as a chapter of mathematics. We can start from a set of propositions whose axioms are assumed to be true by definition, and deduce from them a number of theorems using only logics, as the Euclidean geometry theorems are deduced from the Euclid postulates.

We shall not follow this path. The reason for this is that, while it allows a shorter and quicker treatment and is also logically more satisfactory for some, it also hides the inductive historical trial and error process through which the postulates and the general laws have been discovered. These are arrival rather than starting points. This path has been complex, laborious, and highly nonlinear. Errors have been made, hypotheses have been advanced that turned out to be false, but finally the laws were discovered. The knowledge of at least a few of the most important aspects of this process is indispensable for developing the mental capabilities that are necessary to anybody contributing to the progress of natural sciences, whether they pursue applications or teach them. In any case, we shall mention the names of those that contributed most to the achievements that we will be discussing, along with the date of the discovery and, the first time we meet him, the life span of the author.

A large fraction of the book deals with the physics of fluids. We shall start with their mechanical properties, continue with their thermodynamic aspects, and end up with the statistical mechanics of their molecular structure. In Chap. 1, we shall study the statics and the dynamics of fluids, called hydrostatics and hydrodynamics, respectively. This is, rigorously speaking, a chapter of mechanics, but fluids are much more complex mechanical systems than, for example, the rigid bodies studied in the first volume. As a matter of fact, fluids have an infinite number of degrees of freedom. We shall describe several aspects of the complex fluid phenomenology aimed at understanding the physics rather than the mathematics. The latter requires a knowledge of partial differential equations that is beyond the level of this course.

In the first volume, we learned the fundamental conservation laws of energy, linear and angular momentum. We also saw that the total mechanical energy of an isolated system is not always conserved. It is not conserved in the presence of nonconservative forces. We had anticipated then, however, that the apparent non-conservation of energy is due to having neglected to include all the forms of energy in the balance. In the second chapter of this volume, we shall see that, indeed, energy is always conserved. Thermodynamics teaches us how one must take into account all the possible forms of energy exchange. Two systems can exchange energy not only in the form of work but also in the form of heat. Beyond the mechanical energy, we must also include the internal, or thermal, energy in the balance. The first law of thermodynamics is the law of energy conservation.

Thermodynamics deals with systems that are extremely complex from a mechanical point of view. In order to define the mechanical state of a fluid, for example, one should know the positions and velocities of all its molecules. This is not possible. Thermodynamics describes the state of the system under study with a small number of global variables, like volume, pressure, density and temperature,

and the processes from one state to another considering the heat and work exchanges. In Chap. 2, we shall study, in particular, two important classes of thermodynamic systems, the gases and the solids.

The second law of thermodynamics, discussed in Chap. 3, deals with the irreversibility of natural phenomena. For example, if two bodies at different temperature are brought into contact, heat passes from the hotter to the colder one; the temperature of the former decreases, while that of the latter increases. The opposite process never happens spontaneously. As another example, if we drop a stone from a certain height, it stops when it hits the ground and its temperature increases. It never happens that a stone on the ground jumps up while cooling. We shall learn how entropy, a fundamental quantity of thermodynamics, rules the irreversibility.

In Chap. 4, we shall apply the laws of thermodynamics to several relatively simple thermodynamic systems. After having given some information on the structure of matter and on its aggregation phases, we shall study the conditions for equilibrium between phases (liquid and vapor, liquid and solid, solid and vapor), the transitions between the phases and the surface phenomena.

In the final two chapters, we shall look at the thermodynamic processes from the microscopic point of view, namely considering that the bodies are made of an enormous number of molecules. We shall study statistically the kinematic variables, namely their probability distributions and their average values. In this way, we shall learn that (classical) thermodynamics laws are not independent of (classical) mechanics, but rather logical consequences of same. Historically, the most important steps forward in physics happen when fields that had been separated become unified in a single theory. This had been the case for terrestrial and heavenly mechanics with Galilei and Newton in the seventeenth century, as we saw in the first volume. Similarly, thermodynamics (and chemistry as a part of it) was unified with mechanics in the second half of the nineteenth century by, mainly, James Clerk Maxwell and Ludwig Boltzmann. The study of statistical mechanics will enlighten and give deep physical meaning to several findings within thermodynamics. It shall also lead us to discover the limits of classical mechanics, the limits at which quantum physics takes over.

Each chapter of the book starts with a brief introduction, to give the reader a preliminary idea of the arguments he/she will find. There is no need to fully understand these introductions at the first reading, as all the arguments are fully developed in the subsequent pages.

At the end of each chapter, the reader will find a number of queries, through which to check his/her level of understanding of the arguments put forward in the chapter. The difficulty of the queries is variable; some of them are very simple, some more complex, a few are true numerical problems. On the other hand, the book does not contain a sequence of full problems, owing to the existence of very good textbooks dedicated specifically to those.

The answers to the large majority of the queries are included. However, the solution to numerical problems (without looking at the answers) is mental gymnastics that are absolutely necessary for understanding the subject. Only the effort to apply concepts one has learned to specific cases will allow the reader to master

them completely. The reader should be conscious of the fact that the solution of numerical problems requires mental mechanisms different from those engaged in understanding a text. The latter, indeed, has already been organized by the author; solving a problem requires much more active initiative from the student, a creative activity that is needed for advancing scientific knowledge and its technical applications as well. Consequently, the student should work on an exercise alone, without looking at the solution in the book. Even failed attempts to reach the solution autonomously, provided they are undertaken with sufficient persistence, yield important returns, because they aid in the development of processing skills. If, after several failed attempts, the solution has not yet been reached, it is a better practice to abandon the exercise momentarily, rather than looking at the solution, instead going on to another exercise and coming back to the previous one later.

The following working scheme is methodologically advisable:

1. Examine the conditions posed by the problem in depth. If it is appropriate, make a drawing containing the essential elements.
2. Solve the problem using letters in the formulas, not numbers, developing them up to the point when the requested quantities are expressed in terms of the known ones. Only then should you put numbers into the formulas.
3. Control the correctness of the physical dimensions.
4. When necessary, transform all the data in the same system of units (prefer SI). Use the scientific notation, for example,  $2.5 \times 10^3$  rather than 2500,  $2.5 \times 10^{-3}$  rather than 0.0025. In general, two or three significant figures are enough.
5. Once you have the final result, always verify if it is reasonable. For example, the mass of a molecule cannot turn out to be 30 mg, the speed of a bullet cannot be  $10^6$  m/s, the distance between two towns cannot be 25 mm, etc.

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