

Preface

*Souvenez-vous qu'il n'existe pas de sciences appliquées
mais seulement des applications de la science*

Louis Pasteur

There is no such thing as “applied” science, only *applications* of science. In a time when scientists struggle to trot out the practical outlook of their discoveries, lest they lose any funding opportunity, this firm distinction drawn by Louis Pasteur is right on the mark.¹ When it comes to physics, “applications of science” basically means engineering. I have spent my whole career as a physicist working and teaching in close contact with engineers, many of whom I hold in great esteem. What I mostly appreciate in engineers is their pragmatic attitude towards problem solving, a gift that cannot be regarded as a hallmark of physicists, to make an understatement.

If there is a little criticism that has to be made to some colleagues of mine, however, it is that physics is often seen in engineering classes just as a prerequisite for grasping more technical and specialized subjects. Thus, engineers just try and fill up their courses with as many physical notions as they need without pausing to reflect on their basic meaning, and generally without highlighting the inherent beauty - allow me using this word - of the core physical theories. This happens for quantum physics, but even more for statistical mechanics, in my opinion the “Cinderella” of the background in physics of young engineers.

If this was (perhaps) understandable a few decades ago, the current technological demand has consistently changed the traditional educational requirements in engineering. In fact, the development of sustainable and smart processes for energy harvesting, green chemistry, nanotechnology, bioengineering, health and security require the young engineer an adequate knowledge of the physical processes affecting, at the microscopic level, the structural and thermal behavior of materials.

For over a decade, I have taught classes in statistical physics for diverse curricula in engineering. All along this period, I have had the privilege of dis-

¹ Pasteur’s sentence is the closing remark of a letter addressed in 1872 to the winemakers in Lyon, in which he discusses a scientific question (“why is the taste of the must so different from that of the grape juice”) that is arguably harder to be answered than most of those ones you are going to find in this book.

covering in my classes several brilliant students who, although determined to become good engineers, were also eager to get to the roots of those paramount ideas on which the applications of science stand. I firmly believe that reducing physics to a bunch of application-oriented notions is clipping these bright minds' wings. Hence, this book originates from a kind of bet I have made with myself: namely, that one can also convey, together with those notions required to master advanced engineering applications, the pleasure of discovering the power and generality of the statistical approach to natural processes. Considering the positive and gratifying response of many students of mine, I think this effort was worth being made.

Drawing on the musical analogy that spans the whole volume, I have chosen to expound the ideas and applications of statistical physics in a kind of *crescendo*. Then, while the tone of the early chapters (the short “prelude” on thermodynamics and the real “overture” on Boltzmann’s fundamental assumption) is colloquial, even at the cost of sounding a bit “wordy”, it necessarily becomes more technical as the discussion of more advanced subjects and of specific variations on the main theme (the “fugue”) proceeds. To help the student to follow this *crescendo*, I have tried and introduced some learning aids, which can be summarized as follows:

- a) *Basic requirements.* Usually, student in engineering are not adequately trained in several subjects of general physics that are, on the other hand, crucial requisites to fully appreciate statistical mechanics. To fill this gap, the book contains extensive introductory sections on many topics, ranging from the Hamiltonian formulation of classical mechanics, to basic quantum mechanics, electromagnetic fields in matter, intermolecular forces, and solid state. These helping sections are highlighted with opening and closing “heart suits” ($\heartsuit$). The same symbol is used to indicate those remarks on the historical development of several subjects that, besides properly acknowledging the endeavor of generations of scientists, are, in my experience, highly appreciated by the students.² Math tools and several other complements are presented in extensive appendices.
- b) *Focus on applications.* Scientists aim to understand the world, engineers to *change* it. Practical applications to materials science and cutting-edge technologies are then an essential component of this book, which includes, for instance, brief but informative sections on interfacial properties, phase separation processes, surface adsorption, colloidal suspensions, magnetic materials, superfluidity and ultralow-temperature technologies. Students may also benefit from reading about many clever experimental strategies that have been exploited to reach great scientific results. Hence, emphasis is also put on landmark experiments that have been seminal to the development of thermodynamics, statistical mechanics, and materials science.

² Some of these historical remarks have been a discovery for me too, and may arouse the curiosity of my distinguished colleagues. Take a look, for instance, at the little story about the Dulong–Petit law, or at the graphical sketches of his own model used by Ernst Ising.

c) *Graded learning.* This book is structured to be taught at different levels. The ground level includes most of the content of the first four chapters, and basic notions on phase transitions and open systems, which are the main subject of the following chapters. The latter can entirely be covered in a full semester course, in which several questions posed in the footnotes can also be addressed as exercises. A more advanced teaching level may include those optional “starred” sections where special topics such as the theoretical and experimental investigation of the liquid structure are discussed, and several notes or remarks on subtle aspects specifically highlighted with “spade suits” (♠). Additional texts and selected original papers are recommended at the end of each chapter as suggested readings.

The text is primarily aimed at students of the last year of the master degree in engineering, but it can also provide a broad introduction to statistical mechanics for advanced undergraduate students in physics, chemistry and materials science. Because of the ample presence of the introductory sections mentioned above, and for its conversational style, the book may also be suited for self-learning.

In the course of these years, I profited from discussions with several colleagues about many topics in statistical mechanics. Among them, let me explicitly mention Alberto Parola and Daan Frenkel. The former, with whom I have the privilege of collaborating, can be regarded as my own “reference” theorist. The latter, as a Boltzmann Medalist, does not need any introduction. A special thank goes to my coworkers Enrico Lattuada and Stefano Buzzaccaro, who scrupulously went through the large number of equations in the text, and to my students Gabrielle Housel, Bill Nguyen, and Christopher Canova, who improved my rather uninspired English. Finally, let me thank all the students who, in many years, had willy–nilly taken my classes. Their doubts and comments proved essential to turn a bunch of handwritten notes into the book you have under your eyes.

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