Preface

The subject of this small book is a vast field: continuum physics. Quite naturally, we cannot go into all the details of its many subdomains. Instead, we provide a bird's eye view of the subject .

A continuum is made up of material points. Each material point is a tiny region: tiny from a human point of view, where the natural scale are meters, kilograms, and seconds.

The same material point, however, contains very many particles, atoms or molecules, such that the statistical laws for infinitely many particles apply. In particular, external parameters change relatively slowly such that each material point is always very close to thermodynamic equilibrium.

Thus we deal with fields $f = f(t, \boldsymbol{x})$, where f stands for a property of the material point located at $\boldsymbol{x}$ at time t, such as mass density, temperature, tension, and so forth.

Chapter 1 discusses additive and transportable quantities such as mass, electric charge, momentum, kinetic, potential and internal energy as well as entropy. For each such quantity, a balance equation is formulated and related with other balance equations. Each quantity is described by densities for content, flow, and production. The balance equations must be respected in any case; they apply to all kinds of matter in any state. The highlights of this chapter are the precise formulations of the first and second main laws of thermodynamics in terms of partial differential equations.

Chapter 2 describes the special continuum under discussion with additional field equations, such as Hooke's law, Ohm's law, optical or acoustical properties, the ideal gas pressure relation, and so forth. Each closed set of field equations characterizes a subdomain of continuum physics: elasticity, hydrodynamics, aerodynamics, optics, rheology, thermo-electricity, diffusion, heat conduction, and so forth.

Next we study *Linear Response Theory* (Chap. 3). The reaction of a system in thermodynamic equilibrium to rapid variations of external parameters is worked out in first order perturbation theory. Linear material equations and explicit expression for their coefficients are arrived at, such as the dielectric susceptibility as a function of frequency. Once a tractable model for the system under consideration has been established, these coefficients can be calculated. Even more importantly, there are general relations, such as the Kramers-Kronig or Onsager relations, that can be shown to be true irrespective of a particular model. A highlight of this chapter is the derivation of the fluctuation-dissipation theorem, which is very close to a proof of the second main law of thermodynamics.

In Chap. 4, some standard topics of continuum physics are discussed. These examples serve to familiarize the reader with what she or he may already know, but now on a higher level, such as Archimedes' principle, the first article. Some topics, however, may be new to the reader. For instance, the last article presents a simplified model of a white dwarf. There are articles on crystal optics, the electro- and magneto-optic effect, and on optical activity as well as dielectric waveguides. Metamaterials and photonic crystals are also introduced. Standard problems of elasticity such as beam-bending and buckling, stress enhancement, and vibrating strings and membranes are discussed. The propagation and attenuation of sound waves in elastic bodies and in air as well as surface acoustic waves are dealt with. There is an article on surface plasmon polaritons, and we discuss Ohm's law and the Hall effect, introducing the Drude model. The reader will find sections on the laws of Bernoulli, Hagen-Poiseuille and Stokes and on Reynold's number. An article on local chemical reactions and diffusion introduces the interesting subject of pattern formation. Fourier's classical treatment of a heat conduction problem is presented and thermoelastic effects explained (Thomson, Seebeck, Peltier). Two articles illustrate the dissipation-fluctuation theorem: one on the thermal noise of an Ohmic resistor, and the other on various aspects of Brownian motion. Diffusion, a standard subject in continuum physics, is nothing else but mass-wise Brownian motion. A model of the earth's atmosphere is also discussed.

Chapter 4 could also have been organized into a series of methods of solving partial differential equations. Some can be solved analytically exploiting symmetry, others by rewriting them into systems of ordinary differential equations. The articles on Stokes' law and on stress concentration introduce the potential method. Various Computational schemes such as the finite difference method and the finite element method are also discussed. The sample programs presented are in `MATLAB` because this software package is tailored to the needs of physics.

An appendix covers *Fields*: their transformation properties, how they are differentiated and how they can be integrated over paths, areas, and volumes. After all, continuum physics is formulated in terms of fields and relations between them. There is also a *Glossary*, which may serve as a summary of this bird's eye view of continuum physics. It provides brief descriptions of the main topics of this book and lists most of the people who have entered the stage.

The book systematically presents continuum physics theory (balance equations, material equations, linear response) and substantiates the theory with selected examples. Both parts are of comparable size. On the one hand, the examples cannot be understood without a solid theoretical foundation. On the other hand, physical laws as such are without pertinence if they cannot be shown to be useful for real-world problems—from Archimedes' principle to white dwarfs.

This book can be read in practically any order. It is more like a web than an exposition where the next step cannot be taken without going over all the previous steps. However, the first few sections on balance equations should be read first and consecutively because they introduce a precise system of notation that is nevertheless more or less compatible with a century-old tradition.

This book on *Continuum Physics* addresses students of physics, engineering, and related branches of science with a general background in calculus and basic physics. It will also serve graduate students and lecturers who want to embed their special field in a wider context.

The book presents the physics of continuously distributed matter in a unified way. We have built and developed a stringent theoretical framework and discussed carefully chosen examples. This will enable the reader to assemble the multitude of principles, rules, laws, effects, and theories of continuum physics—the pieces of a jigsaw puzzle—into a coherent whole.

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