Essential Statistical Physics

This clear and pedagogical text delivers a concise overview of classical and quantum statistical physics. *Essential Statistical Physics* shows students how to relate the macroscopic properties of physical systems to their microscopic degrees of freedom, preparing them for graduate courses in areas such as biophysics, condensed matter physics, atomic physics and statistical mechanics. Topics covered include the microcanonical, canonical, and grand canonical ensembles, Liouville's theorem, kinetic theory, non-interacting Fermi and Bose systems and phase transitions, and the Ising model. Detailed steps are given in mathematical derivations, allowing students to quickly develop a deep understanding of statistical techniques. End-of-chapter problems reinforce key concepts and introduce more advanced applications, and appendices provide a detailed review of thermodynamics and related mathematical results. This succinct book offers a fresh and intuitive approach to one of the most challenging topics in the core physics curriculum, and provides students with a solid foundation for tackling advanced topics in statistical mechanics.

Malcolm P. Kennett is an associate professor at Simon Fraser University, British Columbia. He studied at the University of Sydney and Princeton University and was a postdoctoral fellow at the University of Cambridge. He has taught statistical mechanics at both undergraduate and graduate level for many years and has been recognized for the high quality of his teaching and innovative approaches to the undergraduate and graduate curriculum. His research is focused on condensed matter theory and he has made contributions to the theory of spin glasses, dilute magnetic semiconductors, out-of-equilibrium dynamics in ultracold atoms, and the quantum Hall effect in graphene.

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Preface

The ideas of statistical physics allow one to relate macroscopic properties of systems to their microscopic degrees of freedom and play important roles in many branches of physics and other sciences, and disciplines further afield such as economics. In particular, the concept of entropy as a measure of ignorance has found very wide application, especially recently in its relation to information theory. Statistical physics is hence one of the core courses in many undergraduate degree programs, sometimes taught as a combined course with thermal physics, but often as a course in its own right.

As an instructor for an upper-level undergraduate course in statistical physics, I have found it challenging to find a text for the course that contains the important ideas of statistical physics at a level the students can relate to, and at an affordable price. My goal in writing this book has been to cover key concepts and examples in statistical physics in a pedagogical and clear manner, to include mathematical detail in a way that is useful to upper-level undergraduates and beginning graduate students, while also being concise and affordable. This necessarily leads to a limited scope. Unlike many existing texts on statistical physics, I do not try to cover thermal physics and statistical mechanics in the same book, nor do I try to be comprehensive in covering both undergraduate and graduate statistical mechanics in the same volume. My goal is that this book is one that will provide students and instructors with the essential ideas of statistical physics in a way that will prove useful to all students. For students continuing to graduate studies in physics and related topics I aim to give a comprehensive coverage of ideas that are needed in graduate school, and for students who do not continue to graduate studies I aim to give a solid background in statistical physics that will allow them to apply these ideas in other contexts.

The book is based on lecture notes for a one-semester (13 weeks, 3 hours of lectures/week) undergraduate course on statistical physics that I have delivered three times at Simon Fraser University (SFU). I have assumed that the reader of the book has already taken (or is taking at the same time) a course in thermal physics, so I do not elaborate greatly on thermodynamic quantities, although I have included a brief primer on thermal physics in Appendix B, so that the reader can look up ideas as needed. I also assume that the reader has taken at least one quantum mechanics course, so they are familiar with the solution of quantum mechanical problems like the particle in a box and the simple harmonic oscillator. My target audience for this book is primarily undergraduate students learning statistical mechanics for the first time. However, I also believe that it will be of interest to graduate students wanting a clear reference for statistical mechanics that provides details of calculations and clarification of concepts, and to instructors looking for an affordable, well-structured text or reference for statistical physics courses.

My choice of content is what I consider to be the main ideas and examples of statistical physics that will allow a starting graduate student in physics to have a solid foundation in the subject, but is not intended to be exhaustive. Hence, after an introduction to probability, microstates and macrostates (Chapter 1), I cover the microcanonical (Chapter 2), canonical (Chapter 4) and grand canonical (Chapter 6) ensembles. I take the opportunity to discuss Liouville's theorem and ergodicity after discussing the microcanonical ensemble (Chapter 3) and give an introduction to kinetic theory after the canonical ensemble (Chapter 5). After discussing the grand canonical ensemble, I introduce quantum statistical mechanics (Chapter 7) and devote a chapter each to fermions (Chapter 8) and bosons (Chapter 9), touching on Bose–Einstein condensation and superfluidity and applications of Fermi statistics to metals and compact stars. Finally, I finish with a brief introduction to phase transitions, broken symmetry and ordering, using the Ising model as the main example, and introduce Landau's theory of phase transitions (Chapter 10). There are problems at the end of all the chapters to help reinforce the concepts discussed in the bodies of the chapters.

I had had a vague notion that at some point I would like to write the book here for a number of years; almost certainly nothing would have come of these ideas but for a meeting with Nicholas Gibbons of Cambridge University Press in 2015. Nicholas encouraged me to flesh out the lecture notes that I had prepared for the course into a text. It has taken several years for that to happen, but I hope you find the end result useful.

In addition to Nicholas Gibbons, I would like to thank everyone at Cambridge University Press who I have interacted with on this project, particularly Liso Pinto, Maggie Jeffers and Rachel Norridge who have helped keep me on track and provided much helpful advice. I would also like to thank Jeff McGuirk and Michael Plischke from SFU, who have shared their experience of teaching statistical mechanics with me, the students at SFU who have provided me with considerable feedback on early drafts of this book, specifically Florian Baer, Matt Wiens, Aidan Wright, Frank Wu and Adrian Yeung, and my father Brian Kennett for detailed feedback on all aspects of the book. Finally, I would like to thank my wife Kaila and my children Heath and Eily for their love, support and patience during the writing of this book, especially in the later stages of writing.