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STATISTICAL PHYSICS

Fundamentals
and
Application to Condensed Matter

Lectures, Problems and Solutions

ARTISTIC VIEW OF A VORTEX

BOOK, 647 PAGES, 15 CHAPTERS, TO APPEAR IN APRIL 2015, BY WORLD SCIENTIFIC

To my wife and our children Samuel, Tuan, Kim and Sarah.

To my mother.

Foreword

Statistical mechanics provides general methods to study properties of systems composed of a large number of particles. It establishes general formulas connecting physical parameters to various physical quantities. When parameters of a system such as interaction between particles and temperature are known, one can deduce its macroscopic properties. In general, microscopic mechanisms leading to interactions are provided by quantum mechanics. The combination of statistical mechanics and quantum mechanics has provided an understanding of properties of matter leading to spectacular technological innovations and discoveries which have radically changed our daily life since the sixties.

This book is based on the author's lectures for students of the third year of the Bachelor's degree in Physics. The second part of the book treats selected advanced subjects taught at the Master's level. In each chapter, fundamental notions and techniques are presented and followed by applications chosen among frequently encountered phenomena. Demonstrations leading to main results are given in details.

In the first part, after an introduction of basic definitions and mathematical tools (chapter 1), the book covers the foundation of statistical physics at equilibrium: starting from the fundamental postulate, the book deals with systems under various situations going from isolated systems (chapter 2) and systems maintained at a constant temperature (chapter 3) to open systems (chapter 4). The main properties of free fermions (chapter 5) and free bosons (chapter 6) are studied to a great extent. The first part ends with chapter 7 where the method of second quantization is shown. This method, though conceptually more abstract than the Schrödinger equation, is technically less cumbersome to handle, and is very useful in the study of weakly interacting many-particle systems. A large number of applications of this method is found in the remaining chapters.

In the second part, advanced techniques and applications in condensed matter are presented. Selected topics in condensed matter include vibrations of atoms in crystals, conducting electrons in metals and superconductors, band structures in semiconductors, and magnetic properties of materials. Statistical physics contributes with quantum mechanics to the success of these fields in the last fifty years. In chapter 8 the crystalline symmetry is presented with all necessary notions for studying properties of electrons and atoms in crystals. In chapter 9 systems of interacting atoms in crystals are considered. Quantized atom vibrations are called phonons which dominate thermodynamic properties of solids. Systems of interacting conducting electrons are studied in chapter 10 along with general properties of Fermi liquids. The origin of energy bands of electrons in semiconductors is shown in chapter 11. Conducting electrons are at the heart of charge and spin transport phenomena with an enormous number of applications. The spin carried by an electron plays thus a very important role in condensed matter physics. Magnetic properties due to spins cannot be separated from other properties of matter. Note that systems of interacting spins constitute one of the most important subjects in statistical physics. They are studied in chapter 12 where collective excitations, called spin waves or magnons, are shown in details. The abundance of magnetic materials, natural or artificial compounds, provides an inexhaustible source of applications. Chapter 13 deals with the phase transition in spin systems where basic notions such as symmetry breaking and universality class are introduced. The mean-field approximation and the Landau-Ginzburg theory for second-order phase transitions are presented. The concept of the renormalization group is described. In chapter 14, the Ginzburg-Landau theory for the superconductivity is developed to explain properties of type I and type II superconductors. The microscopic Bardeen-Cooper-Schrieffer theory for conventional superconductors is presented in details in this chapter. The second part of the book ends with chapter 15 where basic notions on systems out of equilibrium and the Boltzmann's equation are introduced. As applications of the Boltzmann's equation, properties of electron transport in metals and semiconductors are studied to a great extent.

In the third part of the book, solutions of problems are given. These problems are conceived for self-training and to help the reader discover new related phenomena which are complementary to the lectures.

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Acknowledgments

I am grateful to my many colleagues at the University of Cergy-Pontoise for sharing uncountable stimulating moments in my professional life and for their precious friendship during the last 25 years. My sincere gratitude goes to all the people who have contributed in one way or another to forging the site into the education and research institution that it is today. Thanks to them, it is the place where I go to work every day with enthusiasm and eagerness.

I am in particular indebted to numerous administrative staffs who have been working with me over the years, for their generosity and for carrying out with me our collective duties in joy and mutual trust. I am proud of what we have achieved together. It was always a team effort which is key in overcoming obstacles and fighting adversity.

I would like to express here my deep affection for my former and current doctorate students with whom I shared innumerable wonderful moments not only in our research activities but also in discussions on many subjects of life.

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