Preface

This book describes the main topics in contemporary condensed matter physics in a modern and unified way, using quantum field theory in the functional integral approach. Rather than developing general formalisms and giving formal derivations, an informal presentation is chosen based on analogies and generalizations of standard results in classical and quantum mechanics and in statistical physics.

The book highlights symmetry aspects in acknowledging that much of the collective behaviors of condensed matter systems at low temperatures *emerge* above a nontrivial ground state which spontaneously breaks the symmetry of the system. Such a breakdown of a continuous symmetry usually leads to gapless Nambu-Goldstone modes, which endow the system with long-range correlations, and to topologically stable defects. These emerging properties are responsible for most startling phenomena in ordered states.

Field theories that provide an *effective* description of the condensed matter system under study take the central stage in this book, where the word effective is used in the double sense of being efficient, i.e., productive with minimal effort, and powerful. Such a description is viable because the details at microscopic length and time scales are often irrelevant for phenomena at long wavelength and low frequency. Such phenomena are often dictated by universal laws instead. The topics are studied typically by starting from a microscopic model. Irrelevant degrees of freedom are subsequently integrated out perturbatively to arrive at the effective theory. The physical properties of the system under consideration are finally extracted from the effective description, emphasizing their emerging nature special to the long wavelength, low frequency corner.

To implement this program, simple, yet powerful calculation tools rooted in the functional integral approach to quantum fields are presented. One such tool is the derivative expansion method which is repeatedly used to integrate out irrelevant degrees of freedom. Often these are fermions. For fermionic condensed matter systems at low temperatures, one-fermion-loop contributions to the effective action can have profound implications which the derivative expansion method efficiently summarizes in an effective action. The method is completely equivalent to evaluating Feynman diagrams, and has the advantage of being straightforward to implement.

In conjunction with the emphasis on effective theories, the modern approach toward renormalization is taken, in which a wave number cutoff is introduced to set the scale beyond which the microscopic model under consideration ceases to be valid. In this approach, the cutoff is taken seriously and kept finite (as opposed to taken to infinity at the end as is traditionally done in particle physics). The effect of the unknown physics above the cutoff is incorporated by redefining the parameters of the original theory.

The independent presentation, free of historical constraints and based on functional integrals, allows for a compact and self-contained treatment of the main topics in contemporary condensed matter physics, most of which have been recognized by Nobel Prizes in Physics. It was deemed not appropriate to include exercises. Often these are used to hide technical details. In this book, which aims to also be practical, many technical details are explicitly worked out instead to strengthen and widen the calculation skills of the students. Including these details was also deemed appropriate as some of the techniques used have their origin in particle physics, and despite their virtues, are not commonly applied to condensed matter physics. Their use reflects the author's joy in obtaining results more easily and faster than the more standard derivations. References are relegated to the Notes at the end of each chapter and are not included in the running text to avoid interrupting the flow of the presentation. Although original references are sometimes given, no attempt is made to systematically cite the original sources. The prime purpose for including references in this book is to point students to sources that may be helpful to them. Frequently, those sources are cited where a similar approach is taken as advocated here. Excellent and accessible summaries of most of the topics covered in this book can be found on the official web site of the Nobel Foundation, as well as in the special Centennial Issue of Reviews of Modern Physics, **71**, pp. S1–S488 (1999).

This book has been formatted with the use of L T X, an extended document preparation system that derives from T X, on several computer platforms (HP, IBM, and SUN) running some version of U (N XTSTEP, L , and S). Without the powerful tools that come with the U operating system, this project would never haven been realized. This is especially true for the GNU E editor, or better, programming environment, which is probably one of the most formidable computer programs ever written. Most of the figures have been created with X , a drawing program for the X Windows System, and with G - , an interactive plotting program. Internet search engines, especially G , and the online dictionary and thesaurus provided by the D Development Group were indispensable for this project. I am deeply indebted to all the people that contributed to the amazing pieces of software used in this project.

This book originates from lecture notes written for an undergraduate course on condensed matter physics that I taught at the *Freie Universität Berlin*, Germany during the winter semester 1995/1996. The lectures were repeated as a crash course at the *Universidade Federal de Pernambuco*, Recife, Brazil in March 1996. I am grateful to Professor G. Vasconcelos for inviting me and for a grant from the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq). I thank him and the other members of the Physics Department for their warmheartedness.

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Chapters 2 and 4 served as a basis for a two-hour undergraduate course on Bose-Einstein condensation that I taught at the *Universität Leipzig*, Germany during the summer semester 2004. I am indebted to Professor W. Janke for arranging a visiting professorship and for providing a stimulating and pleasant environment.

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