Preface

Felix Bloch (1905-1983) was one of the great men of twentieth-century physics. He laid the foundation for the theory of solids and may truly be considered the father of solid-state physics. He played a central role in the theory of magnetism. With Alvarez, he measured the magnetic moment of the neutron. His work on nuclear magnetic resonance was recognized by the award of a Nobel Prize. With Nordsieck, he provided the key insight into the resolution of the infrared problem in quantum electrodynamics. Any one of these accomplishments constitutes a major lifetime achievement. Only a handful of scientists have achieved as many.

Felix Bloch was also one of the giants of Stanford University. He was the first faculty member to receive a Nobel Prize, and for work done at that institution. During his years at Stanford, Felix Bloch taught a course on statistical mechanics many times. In going through his papers, I found problem sets dating back to Spring Quarter of 1933-34. Bloch's first-year graduate course on statistical mechanics was a highlight of the graduate career for several generations of Stanford students.

Statistical mechanics is a powerful subject. It is the key to understanding the physical behavior of the many-body systems making up the world around us. The basic goal is to relate the physical properties of a macroscopic laboratory sample in thermal equilibrium to the detailed dynamical behavior of the atomic and subatomic systems constituting the sample. The number of such constituents is generally vast, comparable to Avogadro's number $N = 6.023 \times 10^{23}/\text{mole}$. Ordinary experience gives us very little feel for this magnitude, yet it provides the basis for equilibrium statistical mechanics. Once the fundamental principles are understood, statistical mechanics immediately relates microscopic behavior to physical observables.

Precisely these fundamental principles lay at the heart of Felix Bloch's course. The principles were initially developed by J. W. Gibbs in his classic work *Elementary Principles of Statistical Mechanics*, published in New York in 1902. Felix was fond of saying that in preparing this course he spent most of his time and effort trying to understand and interpret Gibbs (whom, incidentally, he considered the first truly great American physicist). The course always included applications, but specifically to illustrate the principles. On many occasions, Felix said that it was not a course on applications of statistical mechanics, and a reader who seeks the latest developments in critical behavior, or spin systems, or lattice-gauge theories, is bound to be disappointed.

After retirement, Felix spent the last ten years of his life working on a book based on this course. It was not completed. For one thing, new physics problems continued to absorb his attention. For another, he continued to develop and refine his interpretations and explanations. He was never satisfied, and the complex concepts of coarse-grain and fine-grain averages, of ergodic, quasi-ergodic, and sufficiently ergodic systems, and of the statistical significance of entropy, run through his lectures from the beginning. They were developed and refined each time they were presented. When he discovered a new (and elegant!) algebraic proof of Liouville's Theorem, Felix abandoned the first part of the manuscript and started over, incorporating the new development.

Before his death, Felix Bloch told his son George to use his discretion in the disposition of the existing notes and manuscript. After Felix's death, his wife Lore received inquiries about the possibility of finishing the manuscript and bringing it to publication, and she asked my advice on the matter. I looked over the existing written material and all the old lecture notes that Felix had meticulously written out by hand. The second version of the written text consisted of 72 single-spaced pages, and the coverage of the material extended through thermal averages. There was a long way to go, but the lecture notes were so good, so clear, and so interesting, that I decided I would like to undertake this task myself. In June 1984, Lore and George Bloch, Marvin Chodorow, and I agreed that I should complete the book.

My good friend and colleague Brian Serot had taken the course from Felix in 1976 as a graduate student at Stanford. In Brian's fashion, he had taken a detailed set of notes, and he graciously allowed me to use them in preparing this manuscript. I have done so. My first task was to work through Brian's notes to see the course from the student's point of view. I then worked through all of Felix's lecture notes, the first complete handwritten set dating from 1949, and the most complete and compelling treatments occurring in the 1969 and 1976 versions. I decided to use Bloch's material to construct a one-quarter lecture course. I then wrote up those lectures as a book. In my opinion, three of the detailed developments in the original written manuscript detract from the flow of the lectures, and I have taken the liberty of including this written material verbatim in a series of appendixes. The proof of Liouville's Theorem included in the text is from the 1976 lectures.

Classical statistical mechanics is developed first, and Bloch follows Gibbs' approach utilizing the canonical ensemble. Classical mechanics is reviewed, phase space defined, and Liouville's Theorem proven. The concept of an ensemble of systems is introduced, and thermal equilibrium is related to the constancy of the distribution function. The appropriate averaging in phase space is discussed, and arguments given that lead to Gibbs' canonical ensemble. Energy and work are identified as mean values, and the first and second laws of thermodynamics are used to relate thermodynamic functions to the partition function, which is the desired goal. Applications of classical statistical mechanics include the ideal gas, the virial theorem and non-ideal gases, the equipartition theorem, rotations and vibrations of diatomic molecules, vibrations of solids, electromagnetic radiation in a cavity, and magnetism.

Quantum statistical mechanics is then developed in direct analogy with the classical approach. The basic principles of quantum mechanics are reviewed and the density matrix identified. Quantum phase space is defined in terms of the expansion coefficients in the wave function, and used to introduce the quantum ensemble of systems. This provides a basis for evaluating the statistical average of the density matrix. Thermal equilibrium is related to the constancy of the statistical density matrix. An appropriate average in the quantum phase space again leads to Gibbs' canonical ensemble. A parallel argument then expresses thermodynamic functions in terms of the quantum partition function. The previous examples are revisited in the quantum domain. Finally, the theory of quantum Bose and Fermi gases is developed.

No attempt has been made to include a list of references in the text. (The text references that do appear are meant only to point the reader to a more extensive discussion of a topic at hand.) Rather, a list of selected basic texts and monographs has been included at the end of the book in Appendix E. In that appendix, an attempt has been made to include books or monographs discussing some of the fascinating recent work on statistical mechanics, including phase transitions and critical phenomena, chaos in classical and quantum systems, and lattice gauge theories of quarks and gluons. The interested reader can find further references to pursue in these works.

This book contains over 85 problems, including all the distinct problems assigned by Felix Bloch over the years (a few of which now overlap the text) and some added to supplement the text.

The book assumes a fair degree of sophistication in classical mechanics, although the necessary material is developed in the text. It also assumes a familiarity with the basic concepts of thermodynamics and quantum mechanics. Within this framework, the book should be accessible to anyone in the physical sciences.

Statistical mechanics is unique among topics in physics, involving concepts and principles unlike those that students will meet in their other physics courses. It is important to understand these fundamental principles, which are still under active investigation today, and which form the basis for much of modern research. Statistical mechanics lies at the heart of all areas of natural science, including physics, chemistry, and biology.

If I were to teach statistical mechanics again at either the advanced undergraduate or graduate level, I would use this book and supplement it with one or more books describing selected modern applications. The fundamentals do not change.

My motivation for undertaking this project is that I consider Felix Bloch to be one of the dominant scientific figures of our era, and I feel his insight into the fundamental principles of statistical mechanics is worth sharing with those who are eager to learn. Writing did not come easy to Felix. He agonized over the precise form of everything he put down on paper. It would be presumptuous of me to imagine that I could capture the totality of his thoughts on this subject. I write this book out of respect for the man, and with a firm conviction that others will share my pleasure and satisfaction in his insights. Needless to say, the insights are his, and any misrepresentation or misunderstanding is mine.

This project could not have been completed without the assistance of Lore Bloch, George Bloch, and Marvin Chodorow. Brian Serot's notes were invaluable, as was Sandy Fetter's help. Their contributions and support are gratefully acknowledged.

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