

# Introduction

A traditional physics education includes material in thermodynamics, kinetic theory, statistical mechanics, and hydrodynamics, each in its separate course or portion of a course. Other, weakly related, courses describe quantum mechanics, condensed matter physics, atomic and particle physics, and perhaps plasma physics, differential equations, hydrodynamics, etc.

In the meantime, there has been an explosion and a reorganization in the intensity and variety of research in what one might call ‘physical dynamics’. Some workers are developing dynamical systems theory and looking at effectively low-dimensional systems. The low-dimensional problems have a myriad of applications to fundamental understanding of chaos, to medical diagnostics, to understanding market dynamics. Others are looking at fascinating properties of condensed matter systems, as for example the nature of glasses, cascade processes in low temperature systems, fluid turbulence, the fracture of materials, and earthquake or avalanche dynamics. In each case, the dynamical processes involved are analyzed with statistical tools with the analysis and the dynamics being the joint subject of the research. Similar subjects and similar methods are studied far from the boundaries of conventional condensed matter physics. Studies of star counts should be aimed at an understanding of the time-development which produced the stars and its manifestation in the statistics of counts. Particle theory develops its methodologies in parallel to those of condensed matter physics, so that the study of phase transition, of interface motion and of crumpling is the joint domain of both groups of scholars. In one example, renormalization ideas have been jointly developed by both groups. Thus I argue that we must think anew about how to present the material in the parts of physics which involve the fundamentals of dynamics and its statistical analysis. In fact, despite the straw man erected by my opening words about the traditional physics curriculum this rethinking has gone on almost everywhere good physics is taught. These notes are intended to be my contribution of the continuing process of modification of our teaching. They are intended to be a partially coherent whole, accessible to someone with some training in undergraduate physics, with some knowledge of the associated mathematics, together with an ample intelligence and curiosity. (Translation: I think the material is hard; I hope it will be rewarding.) I have included much more material than should be covered in a one quarter statistical mechanics course. In fact, there is probably more material than can be covered in two quarters. However, with an appropriate selection, some dynamics and some statistical mechanics could be covered within one quarter. The course includes some topics which are properly parts

of kinetic theory courses, a little which might belong to thermodynamics, some dynamics of the solid state, a few special topics in hydrodynamics, and a little applied mathematics. Because of my own special interests, there is also a large slug of renormalization group material, presented in its ‘real-space’ version. On the other hand, to keep the presentation relatively brief, the book leaves out many interesting topics which the reader and I might have wished to see included.

Whenever appropriate, it uses the results of experiments and computer simulations. The subject is presented from the perspective of a theorist. The exercises are, as usual, also set from the theoretical perspective. (We do not know much about how to train people for the experimental part of the art. What we do know is apparently better conveyed in face to face contacts than in the lecture mode reflected in this volume.) Many exercises ask for computer generated numerical results. It is assumed as a matter of course that each student has access to a computer and can use it effectively.

The material presented here was tried out in two courses I taught several different times at Chicago. One of these is a graduate level survey of statistical physics; the other a rather personal perspective on critical behavior. Thus, this book defines a progression starting at the book-learning part of graduate education and ending in the midst of topics at the research level. To supplement the research-level side the book includes some research papers. Several of these are classics in the field, including a suite of a half dozen works on self-organized criticality and complexity, a pair on diffusion limited aggregation, some papers on correlations near critical points, a few of the basic sources in the development of the real-space renormalization group, and also papers on magnetic behavior in a plain geometry. In addition to genuine classics, I have included a few of my own papers. Although their status as classics is somewhat suspect (since I am not the best judge of my own work) they do serve to illustrate and amplify some of the topics treated here.

The reader will see defects in presentation, in wording, in the figures, and in the use of  $\text{\LaTeX}$ . All the defects are mine. I got a considerable amount of help in squeezing out the defects from Christophe Josserand, Alexi Tkachenko, Vachtang Putkaradze, Konstantin Gavrilov, and Roman Grigoriev.

As a graduate student I learned statistical physics from my Professors, Paul Martin and Roy Glauber. Afterward I learned from colleagues and from the students and postdocs. I have had the excellent fortune of working with a wide group of people who all care and cared deeply about science. We all share the view that statistical theory can form a small-but interesting-part of an informed view of nature.

As science turns to more and more complex systems, it might be that a statistical approach will become a crucial input to the next generation of scientific issues.

## **Bibliographic Note**

This is a personal view of statistical physics. Some of the material covered comes from my own work. My papers are partially collected in a the volume with the title: *From Order to Chaos: Essays Critical, Chaotic, and Otherwise* — published by World Scientific.

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The second edition will be published early in 1999. Throughout this book, I refer to the second edition with the abbreviation *LPK: Essays*. I also make much use of Cyril Domb's excellent book 'The Critical Point. A historical introduction to the modern theory of critical phenomena'. (Taylor and Francis, London, 1996). This is referred to as 'Domb, The critical point:'. Another very important source is the Domb, Green, Lebowitz multivolume work 'Phase transitions and Critical Phenomena' (Academic Press, Longdon, New York (1971-...)). I shall describe this as *DGL:*. A few reprints are included in the present volume. They are indicated by *REPRINT*.