ing. The cast of characters, past and present, making nuclear policy in India is a lengthy one, and Perkovich seems to have been diligent in exploring the roles, influence, and attitudes of a large fraction of them. He has done so with great sensitivity and in a generally nonjudgmental way, which is quite remarkable, considering his strong personal convictions about nuclear proliferation and many of the actions of India, Pakistan, and the US.

For anyone interested in India's nuclear weapons history, there is no other account I know of that can offer as much as Perkovich's. Read it (the first 443 pages, anyway), and at least thumb through the many endnotes.

## Quantum Phase Transitions

Subir Sachdev
*Cambridge U. Press, New York, 1999. $90.00 (353 pp.). ISBN 0-521-58254-7*

The quantum theory of solids developed over the past 70 years is primarily constructed in terms of weakly interacting electron and hole excitations. This framework works wonderfully in describing simple insulators, semiconductors, and metals. But it is becoming increasingly clear that large classes of new materials—ranging from transition metal oxides, such as the cuprate superconductors, to the heavy fermion materials—are "misfits," which don't conform to the standard paradigm. It is generally believed that a satisfactory understanding of these complex materials will require an incorporation of strong Coulomb interactions and that new—and previously unimagined—quantum phases might be lurking within. In Subir Sachdev's new book, *Quantum Phase Transitions*, such interaction effects are brought to the fore.

Quantum phase transitions separate different quantum phases (phases of matter at zero temperature). Strictly speaking, such phase transitions can be accessed only by a varying parameter—like pressure—at absolute zero temperature. But as Sachdev emphasizes, proximity to a quantum phase transition can sometimes dominate the material properties even well above room temperature. Frequently a quantum phase transition separates two quantum phases having different symmetries, such as the well-studied superconductor-to-insulator transition in thin films. But this need not be the case.

Quantum phase transitions are intrinsically complex, involving the subtleties of quantum mechanics acting in concert with static and dynamic critical fluctuations. As with their classical counterparts, such as the well-studied liquid–gas critical point, quantum phase transitions are blessed with a remarkable degree of universality—an insensitivity to microscopics that emerges due to the presence of characteristic lengths and frequencies well separated from the atomic scales. This happy situation enables Sachdev to focus almost exclusively on comparatively simple but effective models that share this universal physics despite providing an overly simplified caricature of the underlying atomic physics.

Sachdev develops the theory of quantum phase transitions by comparing and contrasting with their classical cousins. By using an imaginary time Feynman path integral approach he recasts these effective quantum models in a form that resembles a classical statistical mechanics problem in one higher dimension. This allows an application of standard renormalization group and scaling techniques, but there are several new and subtle twists, which emerge only in the quantum context. In particular, it is essentially impossible to extract information about real-time dynamics near the quantum phase transition from the imaginary-time formulation, especially on time scales long compared to the critical dephasing time. Progress here requires a direct dynamic formulation in real time, involving a semiclassical particle or wavelike framework appropriate to each quantum phase transition. This area was pioneered by Sachdev over the past decade, and his book contains the first pedagogical account of this important new development.

Another complication particular to quantum phase transitions is the presence of complex "Berry's phase" terms, which reflect the underlying particle discreteness implicit in the quantum fields. Many of the later chapters in the book are devoted to deriving and analyzing the effects of these confusing yet important Berry's phase terms.

Scaling provides one of the most powerful means of attacking strongly interacting many-body problems, and it rightfully plays a central role in Sachdev's book. In Chapter 2, scaling is introduced in the context of familiar single-particle quantum mechanics, allowing even readers unfamiliar with field theory to appreciate its central role. But soon thereafter, the theoretical demands placed on the reader rapidly increase, and later chapters are written at a level that will undoubtedly challenge even the most talented theoretical graduate students.

Toward the end of the book, Sachdev includes a wonderful introduction to the method of bosonization that is clearer than any other I have seen. He also gives an abridged introduction to disordered systems that will enable the reader to appreciate the new subtleties that arise.

Taken as a whole, this book is something of a theoretical masterpiece. With its tight organization, the book leads the determined (and theoretically inclined) reader on a tour encompassing some of the most challenging yet beautiful topics in contemporary theoretical physics. Along the way, the reader is introduced to a remarkable breadth of field-theoretic techniques. Virtually every chapter contains a theoretical "gem," certain to be novel even to the most experienced practitioners. The equations are manipulated with flair and elegance that are testamony to Sachdev's talent as one of the world's premier theorists.

Perhaps the only weakness of this book is that the beauty of the physics can sometimes be obscured by the beauty of the formalism, which flows so readily in Sachdev's writing. In some ways the book is too complete; many readers will almost certainly feel overwhelmed. On the other hand, this book should be required reading for any budding theorist who wishes to explore the quantum wonders of complex materials.

**Matthew P. A. Fisher**
*Institute for Theoretical Physics*
*University of California, Santa Barbara*

## Laser Cooling and Trapping

Harold J. Metcalf and
Peter van der Straten
*Springer-Verlag, New York, 1999. $69.95, $29.95 paper (323 pp.). ISBN 0-387-98747-9, ISBN 0-387-98728-2 paper*

For the past 15 years, the rapid rate at which laser-cooling and atom-trapping techniques were being invented and applied to new problems scared off most would-be textbook writers. The thought was that the field should settle down a bit before a textbook could present it in a proper perspective. As a result, the introduction to cooling and trapping to date has been left to special issues of journals, review articles, conference texts, isolated book chapters, and a few PhD theses.

The spawning of the new field of Bose–Einstein condensation of atomic gases, the awarding of the 1997 Nobel Prize in Physics for laser cooling, and the advent of extensive applications, including the incorporation of laser cooling into the fundamental time standard, and plans to put cold, trapped atoms into space, have all contributed to a changed perspective. The field is established; why isn't there a textbook?

There has certainly been a need: Students entering the field must first understand a core of specialized atomic theory. Then they are faced with the impressive number of ways the theory has been applied to achieve mechanical control over atoms. For instance, the widely known Doppler cooling technique is but one of roughly a dozen distinct laser cooling mechanisms that have been demonstrated. Similarly, there are more than a score of variants on magnetic, optical, and electric field atom traps and a comparable number of atom optical elements. It is a lot to pick out of primary sources without a guide. Hal Metcalf and Peter van der Straten's *Laser Cooling and Trapping* provides the guide.

*Laser Cooling and Trapping* is divided into three parts. The first part is an introduction that summarizes general physics relevant to cooling and trapping. It presents the background topics a student must understand to read the cooling and trapping literature. I find it remarkable that, besides being thorough, it contains essentially no extraneous topics. Despite what must have been a strong temptation to give a little more background here and there, the introduction is consistently on message. Most of its space is used to discuss two-level atoms, optical Bloch equations, and light–atom interactions. The brief discussion of atomic structure is just what you need to know for most laser cooling. The miniprimer on thermodynamics hits only those concepts that tend to crop up in cooling and trapping, such as random walks, the Fokker–Planck equation, and Liouville's theorem. In all, the material in this introduction would typically be gleaned from at least four different texts. It's nice to have it all in one place. Although the discussions in the book are self-contained, students will often need to supplement them with more specialized texts. I think that a chapter-by-chapter annotated bibliography would significantly help students to use the extensive array of references.

The next two parts discuss cooling and trapping and their applications. This array of experiments and technologies is special, in that most of the physical phenomena are exactly calculable. Everything comes down to electromagnetic fields interacting with atoms, or atoms interacting with each other at low energy. Experimental situations may get complicated, but the complete Hamiltonians are known, and the equations of motion can usually be solved.

The book provides the framework for understanding this aspect of laser cooling, but does not dwell on it. Instead, the authors usually opt for simple models and pictorial explanations. Much of the time, cold atoms are batted around by fields as if they were little balls, or they are ideal wavefunctions navigating textbook potentials. And it was the right approach for the authors to take. This flavor of explanation is common in the field, allowing the introduction of a huge range of techniques and applications. Most important: Students should find this approach to physics compelling.

I would be somewhat uneasy if *Laser Cooling and Trapping*, despite its protestations to the contrary, comes to be viewed as a definitive, archival review of past work. It may take on this cast because it does cover so much ground, but the book is not complete; it leaves out some relevant work of comparable importance. Further, the explicit mention of names of scientists and institutions in the text is rather erratic. But for its intended use, which is to guide newcomers into the field of laser cooling and trapping, the book does a superb job. It is organized so as to facilitate updates and additions, and even now, developments since the text was written could probably extend the book by half. Accordingly, I look forward to the second edition. This book is well placed to evolve with the field for many years to come.

**David Scott Weiss**
*University of California, Berkeley*

## Reduced Density Matrices: Coulson's Challenge

A. J. Coleman and V. I. Yukalov
*Springer-Verlag, New York, 2000. $69.80 paper (282 pp.). ISBN 3-540-67148-X*

In a 1959 after-dinner speech at a conference on molecular quantum mechanics held at the University of Colorado, the late Charles Coulson reviewed the state of molecular-structure calculations. Among the topics he discussed was the feeling that a conventional many-electron wavefunction tells us more than we need to know. For energy calculations involving one-electron and two-electron interactions, the equivalence of all the electrons in an $N$-electron system allows a particular pair of electrons to be selected for study, while integration over the coordinates of the remaining $N-2$ electrons removes them from the analysis. This procedure amounts to a construction of the $p$th-order reduced-density matrix (RDM) with $p = 2$ for the two selected electrons. In terms of these, all calculations of physical quantities can be made. The problem is that, whereas it is straightforward to construct the RDM, given the wavefunction, it is not obvious what conditions the RDM itself should satisfy. These would be needed if the RDM were to replace the wavefunction as the basis for a calculation. The way forward was not obvious to Coulson.

John Coleman was stimulated to take up the challenge set by Coulson, that is, to make the RDM the basic starting point for all molecular calculations. In doing so, he established a very active group at Queen's University in Kingston, Ontario. The book under review represents an account of the progress that has been made in the past 40 years, principally from Coleman's perspective. Coleman is joined as co-author by Vyacheslav Yukalov, from the Joint Institute for Nuclear Research in Dubna, Russia, whose collaboration with him on RDM work dates from 1990. The reader's appetite is whetted by the publisher's note on the cover of the book, as well as by the authors' comments in the preface, that there are now algorithms that make it possible to calculate "nearly all the properties of matter which are of interest to chemists and physicists." To bring the reader to that point, the authors set out the steps taken along the way.

The key problem is to ensure $N$-representability, that is, to impose fermionic conditions on the RDM appropriate to a wavefunction describing the $N$-electron system. In discussing this difficulty, the authors adopt a rather formal mathematical style, as well as a specialized vocabulary that reflects the long development of the field. This seems somewhat inappropriate for a text designed (as they say) for first- or second-year graduate students. One wonders how Coulson, whose writing was a model of transparency, would have reacted to it. To get started, students may prefer *Density Functional Theory of Atoms and Molecules*, by Robert G. Parr and Weitao Yang