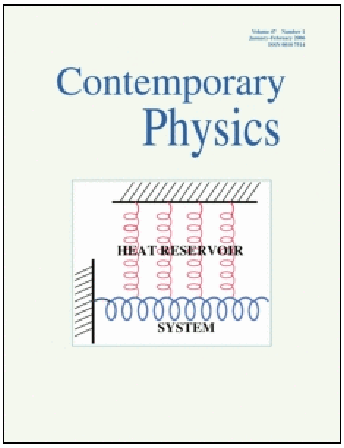

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Quantum theory of finite systems

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Essay reviews

Quantum theory of finite systems

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A review of *Quantum Theory of Finite Systems*, by J. P. BLAIZOT and GEORGES RIPKA. (The MIT Press.) [Pp. xviii + 655.] £44·95.

Many of the older techniques of quantum many-body theory were borrowed and adapted from quantum field theory. This trend was particularly noticeable in the latter half of the 1950's and after the hugely successful development of quantum electrodynamics. There followed a long period of consolidation when these techniques were widely applied and tested with growing success. In this way the subject of quantum many-body theory slowly emerged from its Cinderella-like role as the poor sister of quantum field theory. Finally, the last 5–10 years have seen a rapid period of growth, during which many advances have been made which have greatly added to our understanding of quantum many-body systems. These have taken the form both of developing older methods and of introducing quite new ones. The situation now is that an impressive corpus of techniques and theoretical tools has been built up, much of which has already so successfully been applied to a wide variety of condensed matter systems, that the time is now ripe for applications back in the various realms of quantum field theory itself.

There have been several textbooks which have charted the older methods of quantum many-body theory and its applications. Typical of the best of these is the widely used and respected book *Quantum Theory of Many-Particle Systems* by Fetter and Walecka (FW), which provides a severe measure of comparison for later works. However, very little of the recent developments have yet been incorporated into textbooks, and the appearance of the present book is therefore very timely. There is also no doubt that the present book represents a clean break with tradition in the way that the subject is presented. The book seems to owe no obvious debts to its predecessors, and the authors are to be warmly congratulated on the overall clarity and originality of their approach.

Large though the book is, there is much that it does not cover. This is probably, in itself, strong proof of the many recent developments in the subject, many of which *are* discussed. The restriction implied in the title to a discussion of finite systems is intended broadly to delineate the overall coverage, and perhaps more importantly, the omissions—though the title is certainly open to misinterpretation. For example, one might expect in a book of this title to see a discussion of methods *directly* appropriate to few-body systems (for example Faddeev or Yakubovsky equations), or perhaps to the structure of the atomic nucleus (for example details of the many-particle shell-model) or to atomic and molecular systems of quantum chemistry (for example details of configuration–interaction techniques, geminal wavefunctions, etc.). This book describes none of these, nor is it intended to. Conversely, one might not expect to see a discussion of temperature-dependent many-body formalisms in a book on *finite* systems. That these *are* included is indicative of the fact that nearly all of the formalism described is equally applicable to infinite and finite systems, and in most places (as here) the authors themselves have applications to infinite systems clearly uppermost in mind. The title is, rather, intended to convey the information that what will not be considered are such aspects of the theory as the thermodynamic limit or critical phenomena that specifically arise from the infinite limit, nor indeed such field-theoretic parallels as ultraviolet divergences and their cures.

Most importantly, the book contains virtually no applications to real physical many-body systems. To separate the formalism from the applications is very much in the French tradition of which the authors are part; but to my mind this is the weakest facet of the book, and is one place where it particularly suffers by comparison with the book by FW (which is itself open to the criticism of not being very physical). The essence of the criticism is that in real applications of quantum many-body theory, the approximations and most methods themselves must be so firmly tailored to the particular system under consideration, that not to discuss real applications at all can lead to a very unbalanced coverage, and can also lead the beginner badly astray. Thus, to be a practitioner of quantum many-body theory, one needs not just to learn the mathematical formalism that this book presents so well, but also to develop a keen physical intuition. My own belief is that the two cannot be so clearly separated as the authors implicitly assume.

So, what does the book cover? It is organised into four main parts which contain respectively the main mathematical apparatus, mean field approximations, perturbation theory, and variational methods based on correlated wavefunctions. In the first part, all of the usual expected topics are covered, including particularly complete discussions of second quantization, the various forms of Wick's theorem, and diagrammatic expansions. A novel aspect of the work is the special emphasis placed here on both coherent states and canonical transformations. Both are well employed in the very full discussion of exactly soluble Hamiltonians that are quadratic in the field operators, that the authors give, and which goes a little way towards filling the gap caused by the absence of physical applications. It is nice also to see the Thouless theorem for fermionic wavefunctions of Slater determinant form, given a full airing here—but one wonders why the analogous theorem for bosons is omitted in a book that aims for completeness in these matters, particularly in view of the recent important use made of the associated Hartree approximation in nonlinear bosonic field theories.

Where the book is perhaps most faithful to its title is in the second part. Here the emphasis is put on topics such as mean field approximations, and such associated phenomena as broken symmetries and collective motions (for example rotations), that are inherent to finite systems. The second part, which is also the largest of the four, deals wholly with self-consistent fields. These play a central role in quantum many-body theory, since they reduce the dynamics of many-body systems to the motion of independent particles in a self-consistent potential. The coverage of this material, which is not easily found elsewhere, is masterful and is easily the best in the book. It includes the expected discussions of the variational techniques for the static Hartree–Fock (–Bogolubov) approximations and for the dynamic time-dependent Hartree–Fock approximation via the stationarity of the action. The discussion on broken symmetries is superb. It is hard to imagine that it can be bettered. Less expected is a nice section on the quantization of time-dependent self-consistent fields. A very unified discussion is made possible here by using the concept of generalized coherent states. There is also a discussion of the method of boson images to map fermion Hilbert spaces into boson Hilbert spaces or vice versa, which is difficult to find elsewhere. However, the discussion here seems to be centred on the generalized Holstein–Primakoff method (without being called this), to the complete exclusion of other methods such as the generalized Schwinger or Dyson mappings which may in practice be much more useful. Finally, there is a good description of the path–integral techniques for the quantization of collective modes and the associated semiclassical approximations.

The third part of the book covers both time-dependent and time-independent perturbation theory, and the associated Feynman and Goldstone diagrammatic techniques, at both zero and non-zero temperatures. Although much of this subject matter is well covered by existing books, even here the authors succeed both in shining new light on the old material and in introducing much new material. For example, use is again made of path–integral techniques, this time for the generating functional (which is the trace of the evolution operator), and it is shown thereby how rearrangements of the perturbation expansions can usefully be found, which are not easily seen using diagrams alone. Even though the discussion is sketchy and very far from complete, it is also nice to see discussions of other such very powerful methods as the coupled cluster or exp(S) method, and of such new work as that associated with parquet diagrams.

Finally, the fourth part of the book deals with variational methods based on correlated wavefunctions, typically of the Jastrow kind. The coverage here seems to be the weakest, and in general not as incisive as elsewhere. Although the reader is introduced to such fairly recent methods as the hypernetted chain-approximation, there is virtually no account of the very important work on correlated basis functions associated with the St Louis school of Feenberg, Clark and co-workers. One should also mention here that the book abounds with well-chosen examples at the end of each chapter. These should be very useful to students.

In conclusion, the book provides a somewhat idiosyncratic coverage of what is admittedly now the vast subject of quantum many-body theory. It includes a discussion of many but by no means all of the modern developments. The standard of presentation is very high, and the book may safely be recommended to the wide audience that it is intended to serve. It is obvious that much thought has gone into the presentation. Both the beginner and the seasoned practitioner will find this book useful, and it seems destined to become a standard work of reference in the field of quantum many-body theory. It has set the tone for the next generation of texts on the subject, and has pitched the standard very high. Later books are now bound to be measured against this one.