Near-field Optics: Growth Too Rapid for a Freeze-frame

Near-Field Optics: Theory, Instrumentation, and Applications

Michael A. Paesler and Patrick J. Moyer
Wiley, New York, 1996. 353 pp. $69.95 hc ISBN 0-471-04311-7

Reviewed by Aaron Lewis

The infant and exploding field of near-field optics has spawned a book that aims to cover the theory, instrumentation and applications in the field. The book, *Near-Field Optics: Theory, Instrumentation, and Applications*, by Michael A. Paesler and Patrick J. Moyer, has the distinction of being a first of its kind.

Near-field optics includes a wide variety of phenomena related to interactions that occur within a distance from a surface that is less than a wavelength of light. In its simplest form, optics in the near-field involves the passing of light through a subwavelength opaque aperture, of nanometers in dimension in the visible part of the spectrum, and bringing this point source of light within tens of nanometers of the surface. By scanning either the aperture relative to the surface or the surface relative to the aperture and measuring absorption, reflection, fluorescence or some other optical phenomenon serially point by point, images can be made with resolutions exceeding the diffraction limit of light. One widely accepted limit enunciated by Lord Rayleigh more than a century ago is that the smallest separation resolvable in an optical microscope is approximately half the wavelength of light, which is about a quarter-micron for visible light. Many fields of science and technology, from microelectronics to genetic diagnosis to information storage and retrieval, have now reached this wall of resolution. Near-field optics demonstrates resolution capabilities that offer hope of attacking this critical barrier to scientific and technological advance. As a result of the development of this exciting field, we now have a pivotal interface between the relatively low spatial resolutions of optical microscopy and the super-resolutions of scanning probe microscopy. This is the area that the book by Paesler and Moyer is intended to cover.

The task is daunting, not because it would be hard to summarize an area that began with two papers in 1984 describing independent investigations (from my laboratory at Cornell and Dieter Pohl's at IBM), but because the field is expanding so rapidly that any attempt to summarize this area at this stage inevitably is obsolete before it is printed. Thus, even though the book admirably covers an area to which the authors have contributed significantly, there is a rapidly changing perspective that the book does not effectively present.

The coverage of certain areas that have not progressed as rapidly, such as the theoretical understandings of near-field optical phenomena, is relatively up to date. In terms of theory, the authors have even included a hint of the developing understanding from a microscopic, quantum-electrodynamic perspective that presently is being pursued and offers great hope of success.

Other, more rapidly moving areas, however, are less well covered. In fact, selectivity and important omissions, are the principal weakness of the book. For example, a chapter is devoted to the enabling technology of glass-pulling-based near-field optical-element production that emanated from the doctoral dissertation of Alec Harootunian at Cornell, but essential, practical folklore is omitted. In addition, normal force-sensing cantilevered near-field optical elements are ignored, while esoteric concepts relating to subwavelength probe production without force-sensing capabilities are discussed. This is particularly difficult to understand, since a critical advantage of near-field optics, besides resolution, of course, is the bridge role that it plays between the low resolution of far-field optical microscopes, with their parallel imaging advantage, and the super-resolution of the proliferating scanned probe imaging techniques, with their serial imaging limitations.

The authors discuss the very interesting use of near-field technology for x-ray concentration and the application of near-field optics to overcoming problems of femtosecond laser focusing, while omitting micropipettes as near-field elements for the difficult problem of 193-nm ArF laser optics, important developments in nonoptical methods of force sensing and most of the exciting methods of external illumination.

In summary, this monograph by Paesler and Moyer is less than inclusive and, unfortunately, does not provide an up-to-date view of the exciting potential of near-field optics as it exists today. The technologies were too unsettled when this book was written to offer the researcher who would like to enter this field a how-to of near-field optics. To learn about this field, one would have to read this work together with a thorough search of past and current literature. Only then would there be some possibility of achieving an effective learning experience.

AARON LEWIS, *of the Hebrew University of Jerusalem, wrote a pioneering paper on near-field optics a decade-and-a-half ago.*

Chaos: An Introduction to Dynamical Systems

Kathleen T. Alligood, Tim D. Sauer and James A. Yorke
Springer-Verlag, New York, 1997. 603 pp. $39.00 hc ISBN 0-387-94677-2

Kathleen Alligood, Tim Sauer and James Yorke's *Chaos* is a well-written book that provides a detailed introduction to dynamical systems theory, with a strong emphasis on dissipative systems and low-dimensional chaotic dynamics. The authors are mathematicians and well known to the nonlinear-dynamics community; in particular, Yorke has for more than 20 years played a seminal role in the development of chaos theory. As might be expected from such a trio, the book presents the mathematical theory with care. The presentation nonetheless retains an introductory flavor throughout, by relying on examples to convey the main ideas.

Theorems are stated and often proved, but in a reasonably humane manner: No effort is made to formulate results in their most general setting, and the proofs are carefully explained. On some points, such as the lambda lemma or the differentiability of the stable manifold, where any proof is necessarily rather technical, the authors provide references in which the arguments can be found. Although the widespread interest in nonlinear dynamics has produced a number of books on the subject, very few offer this level of mathematical detail and rigor packaged within a genuinely introductory discussion.

The organization of the material has several notable characteristics:

Overall, the subject is presented in what I would call reverse order: The opening chapters treat chaos in maps, fractal sets and various bifurcations (such as crises) that arise in the examples; in later chapters, we find flows in one- and two-dimensional phase spaces and a description of the elementary bifurcations from fixed points. I would guess that this order might be hard on some students, but I have not tried it in my own teaching. It is undeniably economical, if you want to get to the sexy topics fast.

While their main focus is on the mathematics and the study of various model equations, the authors convey the relevance to real experiments through 12 "lab visits" that appear as chapter appendices. These are brief sketches of the appearance of the dynamical phenomena when seen in the flesh, with examples chosen from chemistry, physics and biology. A second set of chapter appendices, written in the form of extended homework exercises, expand on the theoretical development of each chapter. These "challenges" include the proof of Sharkovskii's theorem, the application of shadowing to justify numerical computation of chaotic trajectories and the analysis of synchronization between coupled chaotic systems.

In addition to covering standard topics, also found in many other texts, there are quite readable introductions to a number of advanced topics. In the context of well-chosen examples, the authors describe Markov partitions, invariant measures and natural measure, shadowing, periodic orbit cascades and so-called Wada basins (whose fractal boundaries have a structure that is almost beyond belief). Many of these examples derive from the research of the authors. The book concludes with a chapter on phase-portrait reconstruction from experimental time series and a discussion of various embedding theorems.

The book omits some things that I like to include in an introductory graduate course. Surprisingly, the concept of structural stability is not developed. As a result, although the pages are filled with examples of bifurcations, the concept of bifurcation as a change in the topological equivalence class is never formulated. Similarly, Peixoto's theorem on two-dimensional flows is not stated. The discussion of elementary bifurcations for maps and vector fields omits center manifolds and normal forms entirely, so the reader cannot appreciate the full significance of the simple one- and two-dimensional examples. Hopf bifurcation in maps is not presented. The importance of homoclinic points is stressed, but Melnikov methods for detecting them are not mentioned. In a discussion of a damped driven pendulum, the main point of which is to introduce a return map with fractal basin boundaries, the authors miss an opportunity to explain how dimensional analysis allows a model to be simplified. Instead we are told that to obtain the dimensionless model, it is necessary to "use a pendulum of length $l = g$." How to achieve this feat is presumably an exercise for the reader!

I think the text should be quite useful for physics graduate courses and honors-level undergraduate courses, although it contains far more material than could be covered in a single term. By the same token, it is a serious introduction, with wider coverage of the subject than is readily available from any other single source.

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Classical Field Theory: Electromagnetism and Gravitation

Francis E. Low
Wiley, New York, 1997. 427 pp. $59.95 hc ISBN 0-471-59551-9

The two classical fields found in nature, electromagnetism and gravitation, have much in common, but their differences are so great that there have been few attempts to treat both subjects in a single volume. Francis E. Low's *Classical Field Theory* succeeds in doing this in a manner that would make it useful in an introductory course at the graduate level. Overall, I feel that it is a welcome addition to the textbook literature, although, as detailed below, it also has some significant flaws and deficiencies.

The writing style throughout the book is clear, and I encountered very few errors of any kind. A good selection of problems is provided at the end of each chapter. However, there are virtually no "worked problems" in the text, and Low assumes a degree of sophistication for the reader that, in my opinion, is somewhat higher than could reasonably be expected of an average first-year graduate student in physics. Thus, I believe that many students would encounter some difficulties if the book were used as the main text in a course.

The first three-quarters of *Classical Field Theory* is devoted to classical electromagnetism. The level and style are comparable to those of the standard text by J. D. Jackson, *Classical Electrodynamics* (Wiley, second edition, 1975), but Low's book has a greater emphasis on purely theoretical issues and a very significant de-emphasis of applications. As examples of the former, a good general introduction is provided to both classical scattering theory and Lagrangian field theory. The reader will also get a good introduction to Fourier transform methods, which are extensively used throughout the book. In general, most of the mathematical and physical aspects of classical electromagnetism that play a direct role in modern theoretical particle physics are given good, comprehensive treatments in Low's book.

On the other hand, no treatment whatsoever is given of many topics in classical electrodynamics that play a key role in astrophysics, plasma physics and experimental physics. Some examples of these topics are synchrotron radiation, magnetohydrodynamics, wave guides and energy loss by charged particles passing through matter. Another significant deficiency is the absence of any discussion of eigenfunction expansion techniques for solving boundary value problems or obtaining Green's functions. Because of these omissions, it is difficult to see how this book could be used as a text for a course that is intended to serve a broad range of graduate students.

The last quarter of the book treats classical gravitation in a thoroughly ungeometrical manner, very similar in approach, level and style to Steven Weinberg's *Gravitation and Cosmology* (Wiley, 1972). However, unlike Weinberg's text, Low's does not progress beyond the mathematical formalism to the applications of general relativity to astrophysics and cosmology. Much of the underlying simplicity of the theory is obscured in the approach taken by Low, as illustrated in section 7.7, where it is shown that, at any point, the coordinate components of any metric always can be transformed to a pseudo–Euclidean form with vanishing first partial derivatives. As presented by Low, this result appears to be a consequence of a lengthy calculation involving a miraculous equality of the number of equations (namely 40) and