DEPARTMENTS

BOOK REVIEWS

Nonlinear Optics: Basic Concepts

D. L. Mills, viii + 184 pages, illus., index, references, and appendixes.ISBN 0-387-54192-6 (United States and Canada) ISBN 3-540-54192-6 (all other countries). Springer-Verlag, 175 Fifth Ave., New York, NY 10010 (1991) $39.50 hardbound.

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This book is intended for undergraduates and postgraduates to serve as an introduction to the field of nonlinear interactions of electromagnetic radiation with matter. The book should also be of interest to scientists and engineers who want to acquire a foundation in nonlinear optics, including second harmonic generation, inelastic scattering of light, four-wave mixing, the response of nearly resonant two-level systems, pulse propagation in fibers, and chaotic behavior of nonlinear systems.

The first two chapters start with a review of the linear optical properties of materials. The basic relationships of macroscopic electrodynamics and dielectric theory, including Kramers-Kronig relations, are covered. Dielectric dispersion theory and the physics of electromagnetic wave propagation and interaction in condensed matter are described clearly. A brief discussion is also given of the properties of anisotropic dielectrics and spatial dispersion arising from a nonlocal dielectric response to an external electric field.

Chapter 3 gives a general view of the nonlinear dielectric response of materials that follows up on the essential principles and notions developed in the second chapter. The possibility of combination mode generation is demonstrated using the example of second-order nonlinearity. The simple anharmonic oscillator model is used for analyzing the nature of the frequency variation of nonlinear susceptibilities and wave mixing. The book also includes very short notes about the wave vector dependence on nonlinear susceptibilities, followed by some estimates of the order of magnitude of the main values.

Two important examples of nonlinear optical phenomena—second harmonic generation and four-wave mixing—are described in detail in Chap. 4. The treatment emphasizes an analysis of second harmonic generation within a slowly varying envelope approximation, including a consideration of pump-depletion phenomena under phase-matching conditions. Methods of achieving the phase-matching condition are discussed using the example of an uniaxial crystal. This chapter concludes with descriptions of four-wave interactions, including four-wave- mixing spectroscopy and a brief discussion of optical phase conjugation.

Chapter 5 is devoted to stimulated Raman and Brillouin scattering. Both classical and quantum Raman scattering are discussed. The generation of anti-Stokes radiation by four-wave mixing through the Raman nonlinearity is also covered. This chapter would have been more useful had it included a discussion of the important difference between optical and acoustic phonons in light scattering. I would recommend such a consideration in the next edition. This chapter does include the interesting information that the term "Stokes component" was first applied to frequency-downshifted Raman radiation by Wood in 1928 (25 years after Stokes died) by analogy with the Stokes shift in luminescence, although the physical nature of the frequency shift is quite different.

I would like to note that during his life Stokes had a significant reputation in the scientific world, and among his many scientific titles was member of the Military Medical Academy of St. Petersburg. Today, the name of this famous experimentalist from Cambridge is associated primarily with his well-known theorem about the circulation of a vector field around a closed path, which was proven by Stokes in 1854.

Chapter 6 deals with the coherent resonant interaction of the radiation field with matter, including self-induced transparency. The author emphasizes the strong nonlinearity of such an interaction when the electronic structure of the system exposed to the electromagnetic field is perturbed far from equilibrium. First, consideration is confined to the response of an isolated atom to resonant radiation, then the interaction of such an atom with its environment is taken into account. The remainder of this chapter concentrates on self-induced transparency. The sine-Gordon equation is introduced and its simplest solutions for the lossless pulse propagation—kink and antikink— are derived. Especially useful is the inclusion of the area theorem of McCall and Hahn, which describes the final state of the pulse evolution and sets the threshold condition for the realization of self-induced transparency. The general properties of the sine-Gordon equation are discussed at the end of this chapter and in Appendix B.

Chapter 7 is oriented toward wave propagation in optical fibers. An analysis of cylindrical optical fibers serves to introduce the concept of guided modes, dispersion relations of various modes, and the limiting frequency. Unfortunately, the chapter does not mention the fundamental single mode propagating through the fiber at the frequency below the cutoff frequency. This shortcoming makes understanding the topic difficult and slightly disorients the reader. Pulse propagation in optical fibers is described in detail. Because it represents one of the most important topics in the book, this subject fully deserves the attention devoted to it. Discussions of linear theory founded on Fourier analyses and of nonlinear theory founded on solutions of the nonlinear Schrodinger equation are clear, but for the latter equation only a small number of special solutions are considered. The chapter concludes with some recent results on solitons in superlattice dielectric structures—gap solitons. The author himself has made significant contributions to this field and his data are of interest.

The final chapter, which is devoted to chaos, is somewhat brief. The author demonstrates

transition to chaos in the Duffing oscillator and mentions the essential means by which chaotic behavior is achieved in nonlinear systems. Some examples of chaos in optical systems are also given.

Appendix A is devoted to the general structure of the wave vector and frequency dependent dielectric tensor. Appendix B reviews some aspects of the sine-Gordon equation.

The book provides problems at the end of each chapter, and the reader will gain a better understanding of the topics covered by working these problems.

The book does have some minor shortcomings that should be mentioned. The part of the text that covers experiments is too brief. A reader interested in the experimental and engineering aspects of nonlinear optics certainly will need to supplement his reading with other sources, including the material given in some of the references. I was surprised that, although the material is described in an absolutely correct way, the author does not provide traditional definitions of the notions of nonlinear optics, for instance, an explanation of the Kerr effect.

In summary, the book is a clear and good introductory text on the important and rapidly growing field of nonlinear optics. The presentation of material is logical and well organized, enabling anyone with knowledge of elementary quantum mechanics and electromagnetism to follow the development of nonlinear optics. The book will be useful for students as well as for scientists and engineers working in the field of the interaction of electromagnetic radiation with matter.

Nonlinear Optics

Robert W. Boyd, 446 pages, illus., index, bibliography, and three appendixes. ISBN 0-12-121680-2. Academic Press, 1250 Sixth Avenue, San Diego, CA 92101 (1991) $59.95 hardbound.

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With the field of nonlinear optics approximately 30 years old, the subject is now becoming a standard part of optics curricula. There are relatively few modern textbooks, including problem sets, that serve as an introduction to this subject. *Nonlinear Optics* by Robert W. Boyd is, therefore, a welcome addition. He states that his purpose is to provide a textbook for the beginning graduate level student, stressing fundamental concepts. For the most part I believe he has done an admirable job of achieving this goal. Boyd treats most of his topics thoroughly and comprehensibly, including physical insights I have not found elsewhere. He provides a good selection of problems to enhance the student's understanding, although he does not include as many numerical examples as I would like. Although I prefer meter-kilogram-second units to the Gaussian units used by Boyd, he does give an excellent discussion in an appendix on the various units used in the field and conversion formulas for susceptibilities.

The first chapter introduces the concept of an electric susceptibility and qualitatively describes nonlinear optical interactions. I found the discussion of degeneracy factors in the nonlinear polarization to be excellent. This is the first time I have seen an author relate this to the number of distinct permutations of the different *fields*, even when some of the interacting frequencies are degenerate. He also gives a nice physical interpretation of this. Unfortunately, he then confuses the subject by defining the degeneracy factor, as do other authors, by the number of distinct permutations of the frequencies.

In the second chapter, Boyd describes the propagation of waves in second-order nonlinear optical media, with an excellent discussion of the Manley-Rowe relations. In choosing to lump the discussion of all second-order phenomena in one chapter, Boyd perhaps slights this important area (e.g., he only briefly mentions optical parametric oscillators and gives no mathematical treatment). However, I found most of this chapter to be interesting and insightful.

I liked his discussion in the next chapter on the quantum mechanical derivation of the susceptibility. I found his discussion of resonant and antiresonsant terms, the density matrix formalism, decay rates (especially coherence decay), and dispersion to be very interesting and informative. The mathematical level here is probably fairly intense for beginners, but the results could be noted and the details skipped without losing any conceptual understanding of the remainder of the book. Since Boyd devotes quite a bit of space to resonance effects in atomic vapors, I think it would have been good for him to include a discussion of Doppler broadening and perhaps a little bit about Doppler-free nonlinear laser spectroscopy.

In Chap. 4, Boyd discusses the origin of the nonlinear refractive index. I liked this chapter. He gives an excellent discussion of the symmetry properties for isotropic media and the tensor properties of the third-order susceptibility for nonresonant electronic and molecular orientation phenomena. These interesting subjects are not discussed at much length in other texts.

Chapter 5 treats nonlinear optics in two-level media. The development is straightforward and relatively easy to follow, but may again tax beginners. Boyd gives interesting and understandable explanations of several resonance effects (e.g., Rabi oscillations, ac Stark Shift, etc.), but unfortunately he does not make any mention of interesting transient effects such as photon echoes.

In the next chapter, Boyd describes processes and applications stemming from the nonlinear index. The treatment of degenerate four-wave mixing (DFWM) is excellent, but because DFWM has become a standard method for measuring the third-order susceptibility, a discussion of the relevant experimental parameters and techniques would have been nice. Similarly, since the Z-scan technique is becoming more widely accepted for measuring the nonlinear index, a more in-depth discussion of self-focusing would be welcome.

Chapter 7 gives a nice intuitive look at spontaneous scattering processes and acousto-optics, setting the stage for Chaps. 8 and 9. Overall, I liked the treatment of stimulated Brillouin (SBS) and Rayleigh scattering (SRLS) in Chap. 8 and stimulated Raman (SRS) and Rayleigh wing scattering (SRWS) in Chap. 9. Boyd gives a thoroughly rigorous treatment of both absorptive and electrostrictive contributions to SBS and SRLS, but it is probably difficult mathematically for beginners to follow and is less intuitive (especially the hydrodynamics) than most of his other discussions. His treatment of Stokes–anti-Stokes coupling in SRS is also interesting, and although the mathematical development is tricky, I found his explanations much clearer than most authors.

The final chapter of the book is devoted to the electro-optic and photorefractive effects. Although Boyd states that the electro-optic effect can be described in terms of a nonlinear polarization, I was disappointed that he does not show the relation between the Pockels coefficient and the second-order susceptibility, thereby tying this chapter in with the rest of the book. He gives a fairly short but interesting discussion of some photorefractive effects, stating rather than deriving the relevant equations. Therefore, this chapter lacks the detailed treatment given in the rest of the book.

In summary, *Nonlinear Optics* is an excellent textbook for use in introductory nonlinear optics courses. For the most part, the book is well written and easy to follow. It contains many interesting facts and insights concerning nonlinear optical phenomena. Most of the mathematical development is straightforward, and some of the harder parts can probably be skipped by beginners without losing much in the way of conceptual understanding. Though a little heavily weighted in favor of third-order effects, the book gives a good survey of a broad range of phenomena. A course lecturer may wish to supplement the text with additional material on second-order effects.