# BOOK REVIEWS

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## Nonlinear Wave Processes in Acoustics

### Konstantin A. Naugolnykh and Lev A. Ostrovsky

*Cambridge University Press, Cambridge, UK, 1998.*
*x+298 pp. Price: $74.95 hardback and $30.95 paperback.*

The area of acoustics concerned with nonlinear wave propagation is traditionally called nonlinear acoustics. Several books on this subject are available [Zarembo and Krasil'nikov (1966), Beyer (1974), Rudenko and Soluyan (1975), Hamilton and Blackstock (1998)]. The book by Naugolnykh and Ostrovsky provides yet another perspective on nonlinear acoustics, and it is written by two leading experts who have worked in this field for almost 40 years. Perhaps the more novel feature of their book, which is reflected in the title, is that nonlinear acoustics is considered as a branch of nonlinear wave physics. Such an approach appears to be very fruitful, as it permits the application to acoustics of many concepts and results obtained in other areas of nonlinear wave physics (e.g., nonlinear optics).

The book consists of seven chapters. Chapter 1, entitled ''Nonlinearity, dissipation and dispersion in acoustics,'' describes several models illustrating the combined effects of these three phenomena on acoustic waves in various media. Westervelt, simple-wave, and Burgers equations are developed for nonlinear propagation in gases, liquids, and isotropic solids. Besides these results (which can be found in all books on nonlinear acoustics), the authors consider media with internal structure having dimensions small compared with a wavelength, such as liquids with gas bubbles and isotropic solids with empty spherical cavities. It is shown how these microinhomogeneities introduce not only additional losses, but also dispersion and a substantial increase in nonlinearity. The chapter concludes with discussion of ''anomalous'' nonlinearities in elastic solids, which are modeled with stress–strain relations not described by a simple power law. Such nonlinearities are associated with dislocations, grains, and microcracks in the medium. Recent developments in this area are very interesting, and it is unfortunate that only a brief survey of these results is presented.

In Chapter 2, entitled ''Simple waves and shocks in acoustics,'' evolution of nonlinear plane waves is considered when effects of dissipation and dispersion are much weaker than that of nonlinearity. In this case, initially smooth acoustic perturbations transform eventually to weak shock waves. The chapter presents classical results for shock formation and describes the corresponding evolution of the frequency spectrum within the framework of the simple-wave and Burgers equations. Results for propagation of intense noise are also presented. In our opinion, the most interesting part of this chapter is Section 6, where propagation in media with anomalous nonlinearity is considered. Models are presented for media with two different stress–strain relations. The first, based on a modified Burgers equation, describes propagation in cubically nonlinear media. The second model describes waveform evolution in media with a bimodular constitutive law, for which compression and tension are characterized by different elastic moduli. It is shown that the nonquadratic character of the nonlinearity results in many new features connected with shock formation. In the next section, generation and amplification of sound by a distributed supersonic source (e.g., a laser beam) is modeled with solutions of a forced simple-wave equation. Nonlinear effects in standing waves are then discussed, and the chapter concludes with general results for energy and momentum associated with plane waves of finite amplitude.

The next chapter, entitled ''Nonlinear geometrical acoustics,'' is an area in which both authors have considerable experience. An augmented Burgers equation for propagation in ray tubes is developed and applied to spherical and cylindrical waves, and in particular to explosion waveforms. Finite-amplitude propagation in stratified media is considered, and two situations are described. In the first, a plane wave propagates in a direction normal to the inhomogeneous layers, in which case the ray paths are parallel straight lines. Examples cited by the authors include propagation in an isothermal atmosphere and in the solar chromosphere. In the more general case of off-normal propagation, the ray paths are curved. Solutions are developed for a monopole in a linearly stratified medium and a point source in an exponential atmosphere. The chapter concludes with an analysis of self-refraction based primarily on Whitham's approach. One of the interesting effects considered is the formation of discontinuities in the wave front as rays intersect when the propagation speed varies along a single shock front. The phenomenon is referred to as a wave front fracture, secondary shock, or shock–shock.

Chapter 4, entitled ''Nonlinear sound beams,'' begins with the KZK equation and several of its asymptotic solutions. A simple modeling procedure is considered in which nonlinearity and diffraction are taken into account in nonoverlapping spatial regions. This approach was useful for understanding basic nonlinear effects in sound beams before numerical solutions and more recent asymptotic results become available. As reviewed in this chapter, the approach predicts broadening of far field beam patterns due to shock formation. For focused beams it explains why weak nonlinearity increases the peak pressure in the focal region (because of higher harmonic generation) and shock formation causes it to decrease (because of increased absorption). Reflection of nonlinear waves from caustics is also discussed. Unfortunately, none of the results presented in this chapter was obtained within the past two decades, during which time many new developments were reported in both theory and experiment.

The next chapter is entitled ''Sound–sound interaction (nondispersive medium),'' where problems involving multiple-frequency wave interaction in quadratically nonlinear media are considered. The simple-wave equation is used to investigate examples of collinear interaction of a weak wave with sound of finite amplitude. Parametric arrays are described using the classical models of Westervelt and Berktay, in which the primary beams are modeled by simple collimated plane waves, and several experiments are reviewed. In the last section, the parametric receiving array is described and its application to nonlinear acoustic tomography is considered.

Classical nonlinear acoustics is restricted to nondispersive or weakly dispersive media. In Chapter 6, entitled ''Nonlinear acoustic waves in dispersive media,'' the effects of dispersion and nonlinearity are of the same order. Several interesting models are offered for wave interactions in the presence of dispersion. The first model describes nonlinear wave propagation in a medium with frequency-selective absorption. In media with negligible dispersion, all harmonics interact resonantly and the initial signal energy does not couple preferentially with a specific spectral component but is instead distributed over a wide frequency band. Selective absorption of unwanted harmonics permits reduction of the number of spectral components participating in the nonlinear interaction, which in turn offers a means of controlling the nonlinear wave processes. Parametric amplification and generation in waveguides and resonators is investigated using a coupled set of equations for three-wave interactions. The analogous problem has been well-studied in nonlinear optics. Bubbly liquids are considered next. At low frequencies, waves in a bubbly liquid are described by the Korteweg–de Vries–Burgers equation, which admits solutions for solitons. When the

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acoustic frequency is close to the resonance frequency of the bubbles, the dispersion is large and a different model is required. Both situations are discussed. Another dispersive system that allows the formation of solitons is compressional waves in a thin solid rod, propagation of which is described by the Korteweg–de Vries (KdV) equation. The final example considered is a granular medium, and a simple model is proposed for a one-dimensional chain formed by contacting elastic spheres of the same radius. It is shown that when the chain is statically precompressed, the KdV equation is obtained in the long wavelength approximation. When the chain is not precompressed, nonlinear effects are large even at low wave amplitudes. Solitary wave solutions exist in this case as well. Experiments related to most of the aforementioned models are mentioned.

The last chapter, entitled ''Self-action and stimulated scattering of sound,'' is devoted to effects of nonlinearity higher than quadratic order (several such cases are considered in the previous chapters). Quadratic nonlinearity is considered to be negligible in this chapter, although in most practical situations this is not the case. However, under certain conditions the cubic nonlinearity can indeed be more pronounced. Attention is devoted to self-action and stimulated scattering of sound, which are nonlinear effects normally associated with media described by cubic nonlinearity. Equations modeling self-focusing of acoustic beams due to heating caused by absorption are derived and then analyzed using approaches developed in nonlinear optics. Self-action phenomena in modulated waves are also considered by analogy with the corresponding cubic nonlinear effects in optics. The analysis is based on a nonlinear Schrödinger equation. Stability of harmonic waves and the possibility of dark solitons are discussed. The four-wave interaction that produces nonlinear wave front reversal is described, as well as various physical realizations of this phenomenon. Self-action effects associated with bubbly liquids are covered. The last section describes phase locking of nonlinear oscillations.

The style throughout most of the book presumes the reader is already familiar with the foundations of nonlinear acoustics and basic concepts of wave physics, and many equations are presented without intermediate steps. We would not recommend this book to those who wish to learn the elementary principles of nonlinear acoustics, detailed derivation of the main equations, and applications. Although any such text is constrained by limits on length, we feel it useful to note a number of topics that are not considered, such as wave interaction in anisotropic solids, nonlinear surface acoustic waves, radiation pressure, acoustic streaming, and interaction of acoustic waves with other types of waves.

This book is nevertheless an excellent complement to the existing books on nonlinear acoustics. The authors present in a clear and interesting fashion the properties of nonlinear acoustic waves and their dependence on the basic effects of dissipation, dispersion, reflection, refraction, and diffraction. This monograph by K. Naugolnykh and L. Ostrovsky should be very useful not only for acousticians, but also for researchers in different fields of wave physics.

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