Spatial Hysteresis and Optical Patterns

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With 149 Figures

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To dear Galya, Alexey, and Marianna

Preface

This book addresses a subject at the crossing point of two lines of investigation – synergetics and modern nonlinear optics. First, the book is devoted to *optical patterns* that previously were mainly attributed to the display of instabilities of homogeneous field distributions. Second, we deal with *optical bistability* and *hysteresis*, which historically were studied predominantly for point (lumped, spatially nondistributed) systems.

In the book, which seems to be the first monograph devoted to optical patterns, I attempt to demonstrate that the variety of optical patterns and other synergetical phenomena is especially rich in spatially *distributed* bistable systems, and that instabilities of homogeneous states are not necessary for the formation of the patterns. Of special interest are patterns such as *dissipative optical solitons*, which individually have particle-like features and when combined resemble molecules, crystals, biological objects, and even social groups.

Another essential point is the key role of *inhomogeneities* of bistable systems. As for hysteresis, it has been studied mostly in point systems, in which, with fixed characteristics of the input signal, one of several sets of steady-state output signal characteristics can form, depending on the prehistory. In spatially distributed optical systems, the kinetics of hysteresis acquires the form of "*spatial hysteresis*", or hysteresis of spatial distributions of field characteristics. This problem of "stereoscopic vision" of such hysteresis was solved in optical bistability some 20 years ago, and the concepts proposed were later confirmed and expanded. Consistent description of spatial hysteresis is one of the basic subjects of this book. The concept of spatial hysteresis is fairly general, being applied to various systems with phase transition of the first kind. In optics, this and other types of inhomogeneities allow us to control pattern location and features, being thus of important applied significance.

Optics contributes also a new – *diffractive* – mechanism for coupling of spaced elements of a system, as compared with the *diffusion* coupling typical for chemical and biological systems. This mechanism, with field diffractive oscillations inherent in optics, is responsible for the presence of various spatial structures with unusual properties, which can be observed not only in optics but also in other "coherent" fields.

Of interest may also be the consideration of entirely confined, *three-dimensional optical solitons*, the discussion of the *quantum aspects* of optical bistability and the correspondence between the display of bistability in classical and quantum objects, as well as the possible applications of the phenomena of spatial distributivity for *optical information processing* given in the book.

The book material was used for teaching students specializing in quantum electronics and applied mathematics at the St. Petersburg State Institute of Fine Mechanics and Optics (Technical University). Knowledge of nonlinear optics is helpful, though not absolutely necessary, for the main notions, ideas and approaches are introduced in the book when required. For instance, in the first two appendices, more thorough and up-to-date as compared with standard textbooks, an analysis of certain fundamentals of nonlinear optics is given, including nonparaxial radiation propagation.

The book material is based on research carried out at the S.I. Vavilov State Optical Institute and at the Research Institute for Laser Physics (St. Petersburg). I am therefore grateful to E.B. Alexandrov and A.A. Mak for their support, and to V.E. Semenov, G.V. Khodova, A.V. Fedorov, S.V. Fedorov, A.G. Vladimirov, V.A. Smirnov and my other colleagues – coauthors of the articles – for joint work. During the work I had the pleasure of discussing various problems of bistability and optical patterns with S.A. Akhmanov, M.A. Vorontsov, F.V. Bunkin, F.V. Karpushko, G.V. Sinitsyn, A.V. Grigoryants, Yu.S. Balkarey, M.S. Soskin, H. Gibbs, G. Khitrova, W. Firth, L. Lugiato, M. Brambilla, F. Lederer, L. Torner, Yu. Kivshar, A. Akhmediev, A. Boardman, P. Mandel, C. Weiss, R. Kuszelewicz, and their colleagues.

I would particularly like to express my gratitude to Prof. H. Haken, who has done so much in the field of not only general synergetics, but optical synergetics as well, for his support for turning out an English translation of my book. The English version is a revised and expanded edition, as compared with my Russian book "Optical Bistability and Hysteresis in Distributed Nonlinear Systems" (Nauka, Moscow, 1997). Although many general aspects of the theory were clarified earlier, further experiments were still a desideratum. It would therefore seem fitting that "Spatial Hysteresis and Optical Patterns" appears with the onset of the new millennium, after the impressive experiments on dissipative optical solitons in semiconductor microcavities by C.O. Weiss, R. Kuszelevicz, and their colleagues in the year 2000.

Credit for the final English text version belongs to O.I. Brodovich and S.V. Voronin whose untimely death prevented him from seeing the book published. I am also very grateful to A.G. Samsonov and A.M. Kokushkin for their help in the typesetting of the manuscript.

St. Petersburg,
February 2002

Nikolay N. Rosanov

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