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Resonant Nonlinear Interactions of Light with Matter

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Translated by O. A. Germogenova

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Preface to the English Edition

This book is devoted primarily to the various kinds of resonant nonlinear interactions of light with two-level (or, in many cases, multilevel) systems. The interactions can involve one-photon as well as multiphoton processes in which some combinations of frequencies of participating photons are close to transitions of atoms or molecules (e.g., we consider stimulated Raman scattering (SRS) as a resonant interaction). This approach involves a broad spectrum of problems. Discussion of some of the basic phenomena as well as the pertinent theory could be found, for instance, in such well-known books as the ones due to N. Bloembergen; S.A. Akhmanov and R.V. Khokhlov; L. Allen and J.H. Eberly, and to V.M. Fain and Ya.I. Khanin. The book "Quantum Electronics" by A. Yariv could serve as an introductory guide to the subject. Thus, some of the basic material in the present book will already be well known to the reader who is an expert in the field. There are, for instance, general density matrix equations; two-level model and basic effects associated with this model, such as saturation of one-photon absorption and Raby oscillations; some basic multiphoton processes such as two-photon absorption, SRS, etc.

However, a large portion of this book is devoted to more recent new results which are not very well known. Among them, the reader will find:

a) the generalized two-level model (Chap. 1), which allows one to retain the main features of the two-level approach when dealing with high-order nonlinear resonant interactions (which involve many photons and/or many levels). The equations of the generalized two-level model (later on used in Chaps. 2, 4, 6–8) allow for a drastic simplification in the description of multiphoton resonance interactions of light waves, accounting at the same time for saturation, dynamical Stark shift of the levels, phase relations, the existence of parametric interactions of waves as well as other physical factors,

b) the theory of two-level nonlinear susceptibility which takes into consideration the entire set of off-resonant levels; this leads to such effects as nonlinear shift of resonant levels and "repolarization" (Chap. 2);

c) the analytic theory of relaxation and Rabi oscillations in the two-level system under action of quasi-resonant radiation with time-dependent amplitude and frequency (Chap. 3); this theory allows one to describe interaction of the system with laser pulses having virtually any envelope shape and duration;

d) the theory of dispersion relations (the generalized Kramers-Kronig theorem for nonlinear media); the polarization properties of the nonlinear re-

sponse of the system (Chap. 4), and spatial structure of one-dimensional waves in nonlinear resonant media (Chap. 5);

e) the theory of three-photon (Chap. 6) and four-photon (Chap. 7) parametric interactions which can describe such processes as anti-Stokes SRS, generation of high-order frequency combinations under resonant conditions, which are by now widely used in IR, visible and UV ranges to produce coherent radiation; and

f) the theory of self-action of light (i.e., self-focusing, self-defocusing, and self-bending of light beams), which is based on resonant nonlinear interactions (Chap. 8), in particular, self-action which is due to SRS.

This edition is not just an English translation of the Russian original. The material has been substantially updated and revised. The main change, however, is that new results, based on most recent research progress are added. For instance, the use of a non-uniform electrostatic field to increase gain in SRS is discussed (Sect. 6.4.3); both theory and experiment are presented.

One of the most recent and exciting new results is concerned with novel effects that are due to self-action of light at nonlinear interfaces (Sect. 8.6) and in cross-self-focusing beams of light in nonlinear media (Sect. 8.7). The particularly interesting result of these effects is cavityless optical bistability. Optical bistability (OB) has become a rapidly growing field in nonlinear optics. This is related to the potential of OB systems to perform logic and memory functions as elements of optical computer and optical signal processing systems with extremely high operational speed. The use of cavities in the known OB effects imposes certain restrictions. First cavityless OB effects without these restrictions have been proposed and experimentally verified in recent years.

Acknowledgements related to my own contribution to this book can be found at the ends of Chaps. 3 and 8 written by me while the ones concerning the entire book are contained in "From the authors".

Baltimore, February 1989 *Alexander E. Kaplan*

Preface to the Russian Edition

The present book is devoted to resonant nonlinear optical processes. Such processes are, perhaps, the most complex and diverse phenomena in nonlinear optics. Due to this complexity, the abundance of concrete experimental and theoretical papers did not yet find sufficient consideration in the monographical literature.

Their unified approach towards the determination of the resonant response of matter allowed the authors of the present book to describe consistently and with maximum clarity, all prominent features of the behavior of molecular polarization that arise in complex multiphoton interactions with intense coherent fields. As far as the application of the results to the solution of wave problems is concerned, we would like to make the following remark. Because of the specific form of nonlinear polarization associated with resonances of the medium, the behavior of interacting waves differs so sharply from that of the nonresonant cases that it would possibly make sense to introduce a new branch of electrodynamics (by analogy with, for instance, magnetohydrodynamics). The realization of such a program is beyond the scope of the present book, although it does mark the beginning of such a project.

The authors are actively engaged into research in the field of resonant nonlinear optics and they obtained important results, hence, the reader gets first-hand information on this topic. The book should be equally useful for specialists and for those wishing to become familiar with this rapidly developing and interesting branch of physics.

Academician R. V. Khokhlov

From the Authors

The authors were greatly inspired and encouraged to write this book by the late Professor Rem V. Khokhlov, the former President of Moscow State University and one of the Soviet pioneers in the field of nonlinear optics. He will always be remembered by the authors as an outstanding scientist and a considerate man.

The various fragments of this book were discussed with many of our colleagues and researchers at other research institutions. We greatly appreciate their attention, suggestions, and criticism.

The material of the book is distributed between the authors in the following way: Chaps. 1 (excluding Sect. 1.2.3), 2, 6, and 7 (excluding Sect. 7.2,4) are written by V.S. Butylkin and Yu. G. Khronopulo; Sect. 1.2.4 by V.S. Butylkin, Yu. G. Khronopulo, and E.I. Yakubovich; Sects. 4.1 and 7.2,4 by Yu. G. Khronopulo; Chaps. 4 (excluding Sect. 4.1) and 5 by E.I. Yakubovich; Chaps. 3 and 8 are written by A.E. Kaplan.

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