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Book review

Coherent Nonlinear Optics

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Editors: M. S. FELD, V. S. LETOKHOV

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[pp. i-xv + 377, with 134 Figs.]

We have here a collective work on recent advances in *Coherent Nonlinear Optics* edited by Professor MICHAEL S. FELD and Professor VLADILEN S. LETOKHOV in commemoration of the pioneers of laser optics: Rem V. Khokhlov, former Rector of the Moscow State University, and Sergio P. S. Porto, former Vice-President of the University of Campinas, Brazil, both prematurely departed in 1977 and 1979. The *Journal of Raman Spectroscopy* published* in 1981 a special volume with 50 papers in the honour of S. P. S. Porto's lasting contribution to laser Raman Spectroscopy.

In an introductory Chapter, Professors FELD and LOTOKHOV review the fundamental discoveries which led to the rapid development of laser optics and its applications in physics, chemistry, biology and other branches of science. Also, the various Chapters of the book, written by outstanding specialists in the now rapidly evolving fields of coherent nonlinear optics on the invitation of the Editors, are reviewed briefly.

Chapter II, by M. S. FELD and J. C. MAC GILLIVRAY, is essentially devoted to superradiance and is based on their paper *Theory of Superradiance in an Extended, Optically Thick Medium* (Phys. Rev. **A14** (1976), 1169), supplemented with: (i) a review of theoretical achievements until 1980, (ii) a comparison of superradiance and other cooperational effects, and (iii) an extensive review of existing experiments as compared to the theory. This is a first review of material hitherto dispersed in the original papers. The quantitative treatment employs the semiclassical method, including in the equations spontaneous emission in the form of a supplementary term simulating the production of polarization in the system. Moreover, various assumptions are made regarding the atomic system, pumping, etc. The assumptions are commented thoroughly, and Section 2.4.3 discusses the results of rejecting certain of them. The arguments of the authors are supported by numerical calculations, e.g. the basic eqs. (2.19) are integrated numerically. On some simplifying assumptions eqs. (2.19) go over into eqs. (2.3), which are then solved analytically. The solutions give the essential properties of superradiance. The authors very carefully justify their use of the semi-classical approach; to this aim, they invoke Refs. [230] (POLDER et al.) and [232–34] (GLAUBER et al.), which are based throughout on the quantal treatment and thus do not neglect fluctuational processes. The pulse can be released by fluctuations of photon vacuum or by fluctuations in atomic polarisation, depending on the ordering of the operators. MAC GILLIVRAY and FELD simulate these fluctuations by means of the additional term Λ_p in eq. (2.19 b). As the pulse grows, the polarization becomes great compared with the fluctuations. Moreover, considering that when the number of atoms N tends to infinity the respective commutators vanish, the semi-classical treatment with simulated source turns out to be quite correct. This argumentation appears to be acceptable. Also, the authors quote numerical results, confirming agreement with the quantal description.

Now, what are the merits of this paper? Firstly, the very thorough presentation, then the logical construction of the whole, and the systematic discussion of the above cited assumptions. The experimental part, which this Referee does not feel competent to assess, contains numerous results obtained since 1973

* *J. Raman Spectroscopy*, Sergio Porto Commemorative Issue, Vol. 10, 1981.

and essentially corroborating the semi-classical approach. What are its drawbacks? The Reader unacquainted with superradiance may well remain unenlighted even after reading the article more than once. It is nonetheless brilliant as a review article for the advanced Reader. The starting point already presupposes a high level of knowledge. Certain formulae and equations are introduced underived, e.g. eqs. (2.19) and (2.24).

Chapter III, on *Coherence in High Resolution Spectroscopy* is by Professor V. P. Chebotayev, an outstanding and highly active laser spectroscopist, well known for his monograph on *Nonlinear Laser Spectroscopy* (Springer-Verlag, Berlin 1977), written in cooperation with V. S. Letokhov. The following four methods, applied in nonlinear laser spectroscopy, are discussed: (i) that of saturated absorption, (ii) two-photon resonances, (iii) saturation resonances of stimulated Raman scattering, and (iv) the method of separated optical fields.

Chapter IV *Multiphoton Resonant Processes in Atom*, by G. Grynberg, B. Cognac and F. Biraben, co-initiators of Doppler-free spectroscopy, lays especial stress on the possibilities of applying Doppler-free spectroscopy as a tool of research. By multiphoton resonant processes in atoms, the authors mean situations when "the transition between two atomic levels is due to the simultaneous absorption of many photons, the sum of their energies being equal to the difference in energy of the levels". An introductory note reminds that the theory of two-photon transitions reaches back to Göppert-Mayer in 1931 and that the probability of these transitions is proportional to the square of the light intensity I^2 and that of multiphoton transitions to I^n. Section 4.1. deals with the experimental aspects, noting that the first observations were carried out with radio wave frequencies. The earliest observations in the visible range are due to Abell in 1962, who studied the transition between the $6S_{1/2}$ ground state and excited $9D_{3/2}$ state of cesium induced by the absorption of two photons (6335.5 Å) from a thermally tuned ruby laser. Subsections 4.11, 4.12 and 4.13 deal with the significance of multiphoton processes in broad band laser spectroscopy, the role of selective pumping of excited levels, and that of intermediate levels in multiphoton transitions. These three subsections are of a predominantly technical nature, conveying much concrete information on the transitions themselves and adducing examples of spectra in which multi-photon processes play an important part.

Section 4.2, on Doppler-free two-photon experiments, deals with applications of Doppler free spectroscopy in studies of multiphoton processes. The earliest experiment of this type was performed by Cognac and Biraben in 1974. The theoretical aspects and experimental setup (p. 119) are presented with clarity, and attention is drawn to the possibility of applications to metrology (measurements of isotope shift) and collision processes. Essentially, stress is laid on technical aspects (as is seen as well from Subsection 4.2.5).

Section 4.3, *Theory of two-photon transitions in atom*, discusses the fundamentals of two-photon transition theory on the basis of effective Hamiltonians and the density matrix equation and ends with remarks on the selection rules for two-photon transitions. A comparison with experiment is given.

Section 4.4, *Multiphoton transitions*, is an extension of 4.3 leading up to the selection rules for three-photon transitions. The last two Sections, 4.5 and 4.6, deal with dispersion near two-photon transitions as well as the role of transient processes.

Thus, we have here a rather specialistic article on a uniformly high level throughout. It contains numerous details of a spectroscopic and technical nature (types of lasers used in the experiments, spectroscopic symbolics, lifetimes, linewidths, etc.); the theoretical and experimental material forms a whole, providing insight into the present, strongly expanding technique.

Chapter V, *Coherent Excitation of Multilevel Systems by Laser Light*, written by G. D. Cantrell, V. S. Lotokhov, and A. A. Makarov, considers the interaction of laser light and multi-atomic molecules. For simplicity, the latter are considered as symmetric tops (like e.g. SF_6), and the description employs the standard method of solving Schrödinger's equation with a supplementary coherent pumping term. Solutions are given for systems with discrete, quasi-continuous as well as continuous systems of levels, and are shown to undergo considerable complications if vibrational and rotational states and multiphoton transitions between the levels are taken into account. Solutions can then be obtained for some particular cases only, i.e. for well defined relations between the Rabi frequency and the laser light/resonance frequency detuning parameter. The authors then apply the above results, known from the literature, to a study of the general solution of Schrödinger's equation for a multi-level system with vibrational and rotational states of the molecule, with no limitations on the Rabi frequency and detuning parameter.