

Contents

Two-dimensional quantum statistics of optical parametric processes	13
Jan Peřina and Jaromír Křepelka	
1 Introduction	13
2 Joint generating functions and moments	14
3 Joint photon-number distribution	18
4 Joint wave distributions	18
5 Sum, difference and conditional number distributions	20
6 Time evolution with losses and noise	21
7 Illustrations	22
8 Matrix formulation	24
9 Criteria of nonclassicality and entanglement	27
10 General optical parametric process	30
11 Conclusion	37
References	38
Interference effects for stored photons	41
Andrzej Raczyński, Jarosław Zaremba, and Sylwia Zielińska-Kaniasty	
1 Introduction	41
2 The essence of the Hong-Ou-Mandel interference	43
3 Light propagation in a two-level atomic medium	44
4 Lambda and tripod systems	47
5 Light storage	49
6 Generalized HOM interference	55
7 Conclusions	61
References	61
Invariant-subspace method in quantum optics	63
Vlasta Peřinová and Antonín Lukš	
1 Introduction	63
2 Descriptions of quantum optical processes	66
3 Degree of quantumness	75

4	Invariant-subspace method	80
4.1	Invariant operators	80
4.2	Schrödinger picture	85
4.3	Heisenberg picture	95
4.4	General formulation of method	97
4.5	Reintroducing of the eigenvalues	97
5	Phase mismatch	99
5.1	Slowly-varying operators in the time	100
5.2	Slowly-varying operators in the space	100
6	Three-wave mixing	103
6.1	Heisenberg picture	103
6.2	General formulation of the method	106
6.3	Connection with spectral decomposition	108
7	A glimpse at the Raman scattering	111
7.1	Heisenberg picture	111
7.2	General formulation of method	114
7.3	Connection with spectral decomposition	117
8	Conclusions	120
	References	121

Two-atom Resonance Fluorescence: From Scaling Factor to

Entanglement	123
---------------------------	-----

Zbigniew Ficek

1	Introduction	123
2	Master Equation Approach	125
2.1	Two Models of the Atomic System	127
3	Scaling Factor	131
3.1	Equations of Motion for the Density Matrix Elements ...	133
3.2	Steady-State Solutions	135
4	Fluorescence Intensity Spectrum	137
4.1	Dipole-Dipole Blockade	140
5	Coherence and Correlations	146
5.1	First-Order Mutual Coherence	146
5.2	Second-Order Coherence and Correlations	149
5.3	Anomalous Correlations	151
6	Entanglement	153
6.1	Entanglement Versus Interatomic Interactions	156
6.2	Entanglement Revival	159
	References	161

Coherences induced in Three-Level Systems

Youssef Hamidou and Azeddine Messikh

1	Introduction	165
2	Squeezed Vacuum	168
3	Coherent Population Trapping	171
4	Derivation of Master Equation	175

Contents	9
5 Atomic coherences	183
5.1 Dressed state analysis	190
References	193
Structured continuum in various optical phenomena	195
Cao Long Van	
1 Introduction	195
2 Fano diagonalization as a method for describing the systems with AI levels	197
3 Autoionization from a system with Lorentzian continuum	206
3.1 The model	207
3.2 Photoelectron spectrum	210
4 Photoelectron spectra induced by broad-band coupling laser from a structured continuum	214
4.1 The model with the double Fano system	215
4.2 Photoelectron Spectrum in the case of two Lorentzians ..	221
5 EIT for Lambda-like systems with a structured continuum and broad-band coupling laser	227
6 Conclusions	235
References	235

Preface

Quantum optics was born in the first years of the 20th century. The first papers leading to further ideas of quanta of light were presented by Max Planck and Albert Einstein. Their pioneering papers laid the foundations for the theory of quantum optics. However, one should remember that for the birth of the formal theory of quantisation of light, the development of quantum mechanics was necessary. Interestingly, the word 'photon' appeared for the first time in a paper by a Gilbert Lewis, a chemist, in 1926 and was later used by P.A.M. Dirac, a physicist, the next year. The modern sense of the term quantum optics was established in 1956 when Hanbury Brown and Twiss built the intensity interferometer and performed their famous experiment in which correlations between two light beams were measured. Although the results of their experiment could be explained on the basis of the classical theory of light, with some quantum component to the process of photodetection, their result is commonly accepted as the beginning of the modern quantum optics era. The next milestone in the development of quantum optics was the invention of laser in 1960. The physical properties of the light generated by lasers were considerably different from those characterising the light generated by classical thermal sources. This fact was a great impulse leading to further development of quantum optics' ideas. The first of them were presented in the fundamental papers written by Glauber, describing new states of light quantum coherent states. From that moment we observe a tremendous growth of interest in the investigation on the quantum nature of light and its interaction with matter. We can mention such problems and effects as photon bunching and antibunching effects, problems related to the Heisenberg uncertainty relation, for instance the squeezing of light, phase effects in quantum optics and others. At the end of the 20th century new, fundamental ideas arose and the quantum information theory became one of the most intriguing trends in modern physics. This fact led to theoretical in their deepest sense as well as practical new developments in the field of quantum optics. For instance, optical methods have been designed for the use in quantum computing, quantum cryptography and quantum communication devices. Moreover, we observe a huge progress in methods applying trapped single ions and atoms. Such "single atom experiments" gave huge momentum to the advances in various branches in modern physics and technology. What

is worth mentioning, recent theoretical and experimental achievements in quantum optical research inspired by the quantum information theory made it possible to answer the fundamental questions related to the understanding of the quantum nature of the physical world and *vice versa*, solutions to problems appearing in the field of quantum and atomic optics has affected technology, leading to a new quantum technological revolution.

Although this book is devoted to various problems related to the contemporary quantum optics, this volume is assumed to be the first part of a series of books devoted to the problems related to various branches of physics and their practical applications. The intention of the editor and authors of the papers presented here is to give the reader insight into the topics of physics that are in the mainstream of current investigation. We hope that the forthcoming volumes will cover the subjects that are in the focus of interest of a broad group of students and researchers concerned not only with physics but also with other natural sciences.

Acknowledgments I would like to express my gratitude to His Magnificence Rector of the University of Zielona Góra, professor Czesław Osękowski for his support during the preparation of this book.

Zielona Góra, 2011

Wiesław Leoński