Preface

Prior to the invention of the laser in the 60s, the development in optics was primarily dependent on the development in fundamental quantum mechanics. During the 50s, progress was primarily made in the direction of optical coherence by von Laue, Schrödinger, and Zernike and then by Glauber who has constructed the final form of the quantum theory of coherence. An exceptional case was that of photon bunching as a result of intensity correlation function measurements. This was a major leap in the field, primarily taken by Hanbury-Brown and Twiss in the 50s.
The path paved by this first correlation function measurement has brought new insights into the field of optics in conjunction with such concepts as field coherence and correlations. The HBT experiment received considerable attention from a wide spectrum of physics researchers. With the invention of lasers in the 60s, we came across the realization of a non-classical state, and the examination of its coherence and correlation properties was promising for the possible realization and existence of other non-classical states. Starting from the 60s, advances in laser research stimulated major developments in fundamental quantum mechanics in conceptual as well as experimental directions, and the discipline was often referred to as quantum optics. The idea of squeezed states and the phenomenon of squeezing in the phase space of the field quadrature operators were initiated by the works of Robinson and Takahashi in mid 60s and later by Stoler, Yuen, Caves et al. during the 70s and early 80s. During the mid 70s Mandel and coworkers successfully observed the first photon antibunching effect which was predicted earlier by Glauber in the quantum theory of coherence. The first experimental observation of squeezing was reported by Slusher, Hollberg, Yurke *et al.* in 1985. This was just the beginning of a rich gold-mine in which more non-classical states could be conceptualized and engineered. Number-phase squeezing was introduced by Kigatawa and Yamamoto in 1986 and the race for maximum squeezing began. In the beginning of the 90s, laboratories in Europe and the USA perfected the idea of phase-space squeezing by employing sophisticated techniques, such as quantum non-demolition measurements, which was introduced in the early 70s by Braginsky. About the same time, to study the realistic decoherence effects of pure quantum states interacting with a classical reservoir, Schrödinger cat and kitten states were conceptualized. The developments in non-classical states and their experimental realizations also stimulated major recent progress in disciplines such as atom optics, atomic interferometry, and laser cooling in optical molasses.
Another direction of studying pure quantum effects was paved by the two-level atomic dipoles interacting with a single mode of radiation field. The first example of two-level system was used by Einstein in 1917 in his classical work on spontaneous radiation. Dicke in 1954 studied the cooperative effects in a cluster of two-level atoms interacting with a continuous spectrum of radiation. The quantum properties of light in a cavity interacting with a single two-level system was studied by Jaynes and Cummings in the early 60s. Despite its simplicity, the so-called single-atom maser turned out to be an important tool both in generating and in understanding the quantum behavior of atom-field interactions in charged ion and neutral atom traps using highly excited Rydberg atoms. Photon antibunching, super and subradiation, sub Poissonian statistics, individual as well as collective collapses, and revivals in the time dependence of the photon number are major effects one can study with this simplest atom-field interaction model. The experimental work on single two-level atoms in high quality cavities was initiated by Walther during the mid 80s.

When these atoms are laser-cooled down to virtually zero temperatures, several non-linear dispersive bistabilities in the cavity mode intensity have been recently observed.

Progress in the early 90s on homodyne measurements and detection on the phase-space distribution functions comprise yet another fundamental development in the examination of non-classical states. The basic idea is to extend the conventional tomography to measure the statistics and distribution of phase space operators in the quantum domain by means of rotated quadrature operators. This promising field, although still in its infancy, is undergoing a rapid development as new techniques are introduced to increase the dimensionality of the phase space from two (one degree of freedom) to four (two degrees of freedom), and to higher dimensions.

It is an impossible task to collect all major developments in quantum optics and spectroscopy in a publication of this size. In these proceedings, contributions from eleven authors are presented in a comprehensive textbook style, ranging from orthodox quantum optics to applications in solid state physics and atomic spectroscopy.

In the first chapter, by O. Keller, *Aspects of Local Field Electrodynamics in Condensed Matter* are presented. He starts from microscopic Maxwell-Lorentz equations plus a linear equation describing the material-dependent induced current densities non-local in time and spatial extent. The standard theory of local-field electrodynamics is then discussed and the discourse is extended to the transverse and longitudinal fields, emphasizing the fundamental difference between them. The coupled antenna theory is discussed and the local field effects in mesoscopic media are presented. Applications to one and zero dimensional mesoscopic systems and the photon drag phenomenon in mesoscopic rings are finally examined.

In the second chapter, by I. Kulik, *Persistent Currents and Persistent Charges in Nanostructures* are discussed. The main part of this chapter is devoted to the quantum effects arising from the interaction of the electromagnetic field with mesoscopic metallic particles and rings. Magnetic (time-independent) and electric (time-dependent) Aharanov-Bohm and quantum high frequency effects are then investigated in coupled systems, such as optical fiber and mesoscopic conducting loops.

In the third chapter, by A.S. Shumovsky, *Quantum Optics and Solid State Spectroscopy* are presented. There, the possibility of strongly correlated bosonic excitations, such as squeezed states of photons, is considered and their measurement in optical spectroscopy is elaborated.

The fourth chapter, by H. Walther, discusses *Laser Experiments with Single Atoms in Cavities and Traps.* It starts with a review of the one-atom maser in a high quality cavity including the derivation of the model as well as the cavity photon distribution. A discussion on the quantum jumps of the micromaser field is then followed by atomic interferometry of micromasers. Experiments with ionic traps and ion storage rings are then discussed. Finally, experiments with single laser-cooled ions are presented.

The fifth chapter, by G. Compagno, R. Passante, and F. Persico, is entitled *Dressed States in Atoms and in Excitons.* The authors discuss the concept of dressed atoms in analogy with polaronic excitons in solid state physics. They discuss the topic in the context of a generalized two-level system and examine the population of dressed states. The observational time interval and dynamical time scales in the measurement of such effects are then compared. The authors suggest that the formation of the virtual cloud can be experimentally observed, and the fundamental implications of this result to test partially explored QED processes such as positronium creation and annihilation are emphasized.

The sixth chapter, by A. İmamoğlu, H. Schmidt, R.J. Ram, K. Campman, and A. Gossard, is on *Electron Coherence in Quantum Well Intersubband Transitions*, and stresses the importance of absorption as a fundamental limitation to the novel properties of non-linear devices. They primarily analyze the electron coherence and interference effects in intersubband transitions. The authors propose a double quantum-well structure in order to eliminate the absorption by Fano-type destructive quantum interference and concentrate on two new types of optical devices: semiconductor lasers without inversion and resonant nonlinear devices that generate into a transparent medium.
The seventh chapter, by T. Hakioğlu, is entitled *Interaction of Two-Level Atomic System with a Single-Mode Radiation.* The author discusses the celebrated Dicke model in the equivalent field mode limit and illustrates domains of qualitatively different physical behavior as the number of atoms and the number of excitations vary arbitrarily. The commensurability/incommensurability of the eigenvalues is discussed in a wide range, starting from strong to weak field limits. Interplay between various timescales and their effect on the collective collapses and revivals are examined. The accuracy of the rotating wave approximation is limited by the total number of excitations. Superficial instabilities in the spectrum can be observed if one arbitrarily increases the number of excitations remaining in the rotating wave approximation. It is shown that instabilities are not chronic but can only be cured in the fully unitary model. This requires the proper handling of the counterrotating terms.
In the eighth chapter, G.M. D'Ariano discusses *Quantum Estimation Theory and Optical Detection.* This fundamental problem establishes the necessary marriage between conventional quantum mechanics and the quantum theory of measurement. The author starts with a discussion of commuting and non-commuting phase operator measures and elaborates on Naimark's theorem in two examples. After discussing various detection schemes (direct, balanced homodyne, heterodyne), he discusses the theory of joint measurement of two non-commuting observables. The chapter is continued with a discussion of the quantum estimation theory, and concludes with the study of quantum non-destructive measurements from a generalized point of view.
The ninth chapter, by G.M. D'Ariano, is entitled *Measuring Quantum States.* The author starts with the discussion of the central limit theorem and illustrates the limitations in its use in the calculation of moments of random variables. In the section devoted to quantum homodyne tomography, the author introduces the idea of tomography and extends the discussion to its application in quantum optics. Practical difficulties arising in the numerical extraction of the Wigner function from the marginal probabilities are then clarified. An exact method for the measurement of the density matrix is introduced for certain representations. The author then discusses various measurable representations of the kernel of the Wigner function and calculates their bounds for quantum efficiency. The formalism is then extended to finite resolution, followed by an investigation of the principal problems arising in the recovery of the full Wigner function for a system with a single degree of freedom. A brief discussion of the quantum and classical Radon transform is followed by a conclusion and remarks on experimental applications.
The tenth chapter, by P. Tombesi, is entitled *Optical Tomography and Macroscopic Coherence.* This recently introduced technique is a strong potential tool in understanding the state of a quantum system in the framework of phase-space-analysis. The author first discusses generalized (s-parametrized) Wigner functions and marginal probabilities. Quadrature phase measurements from a homodyne scheme are discussed using a general non-ideal quantum efficiency. The tomographic reconstruction of the Wigner function from

the repeated measurements of the marginal probability distribution and the practical problems arising therefrom are illustrated. The formalism is then generalized to displaced and squeezed quadratures respectively. The non-ideal detector and its influence on the measurement scheme are discussed next. The chapter is concluded with a discussion of detecting optical Schrödinger cats and interference fringes. We believe that the three chapters by D'Ariano and Tombesi will give the reader a good account of the principles of tomography and quantum phase space analysis.
The eleventh chapter, by A. Miranowicz, is on *Harmonic Oscillator States in Finite Dimensional Hilbert Space.* Hilbert spaces in a finite dimension started receiving attention in physics after the introduction of a unitary phase formalism by Pegg and Barnett. The author analyzes finite dimensional coherent states in two different approaches, first by simply truncating the number state expansion of coherent states and later by the action of a generalized finite dimensional Hilbert space displacement operator. The number-phase Wigner function is also analyzed using these finite bases.
Chapter twelve is by A. Serpengüzel, S. Arnold, G. Grieffel, and J.A. Lock, and is entitled *Optical Spectroscopy of Microcavities.* The authors discuss light coupling in microspheres and other microcavities with morphology dependent resonances and they examine efficient coupling mechanisms.

The first idea of organizing a summer school on Quantum Optics and Spectroscopy of Solids (QOSS/95) arose from our discussion with Prof. Barut, when the three of us met in Ankara in September 1994. After his death on the 6th of December 1994, we were honored to turn the organization into a memorial meeting dedicated to his unique personality, and scientific achievements. We should pay our tribute to him for giving the idea and motivating us to start this large organization.
This volume is largely composed of lectures given by the invited lecturers in the *Summer School on Quantum Optics and Spectroscopy of Solids* (QOSS/95), held at Bilkent University, Physics Department, on 2-10 July 1995, with over 100 participants and 13 lecturers. The funding was provided by the Scientific and Technical Research Council of Turkey (TÜBİTAK), the International Center for Theoretical Physics (ICTP), and Bilkent University. We are grateful to all of them for their generous support without which the organization would not have become a reality.
We at last but not least thank all of our lecturers and participants for their participation in this significant event.

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