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Problems of Condensed Matter Physics

Quantum Coherence Phenomena in Electron-Hole and Coupled Matter-Light Systems

EDITED BY

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Dedicated to Professor Leonid V. Keldysh on his 75th anniversary

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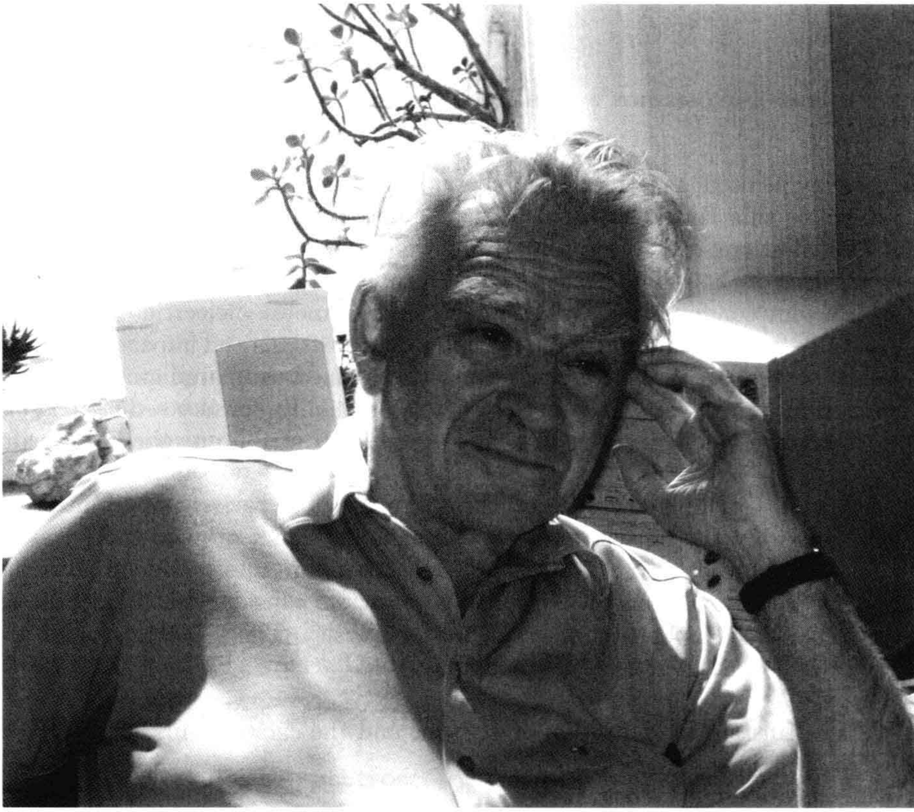
PREFACE

We are very pleased, as former research students of Professor Leonid V. Keldysh, to introduce this Festschrift dedicated to him on his 75th birthday. The brilliant contributions of Professor Keldysh, which include the Franz–Keldysh effect, an electron–hole liquid, the nonequilibrium (Keldysh) diagram technique, Bose–Einstein condensation (of excitons) and a "metal–dielectric" transition, acoustically-induced superlattices, multiphoton transitions and impact ionization in solids, etc., in many aspects influenced and formed the paradigm of modern condensed matter physics. It is also a great responsibility for us to edit the issue: many famous researchers enthusiastically agreed to contribute to the Festschrift.

The key point of the book was to collect a number of review papers in order to spot probably the hottest and most interesting topics of condensed matter physics at the present time. Not surprisingly, there are many references to the pioneering works by Leonid Keldysh. In a sense, we consider the Festschrift as a "guide-book" of modern condensed matter physics. The following topics are covered by the review articles of the book:

- Bose–Einstein condensation of excitons and the excitonic insulator
- Electron–hole liquid
- Metal–dielectric transitions
- Semiconductor and organic quantum wells, superlattices, microcavities and other nanostructures
- Disordered systems in condensed matter
- Many-body theory and the Keldysh diagram technique
- Composite fermions and the quantum Hall effect
- Spintronics and quantum computation
- Resonant acousto-optics of semiconductors
- Coherent optical phenomena in semiconductor nanostructures
- Inelastic electron tunneling spectroscopy

Thus the volume is addressed to a very broad audience of condensed matter physicists, from young researchers to experienced academics. In his article published in this book, Vitalii L. Ginzburg overviews his concept of the "Physical Minimum", a list of research problems of physics and astrophysics which are particularly important, challenging and interesting in the beginning of the twenty-first century. From the condensed matter physics side, the list includes nine problems, 2–10 (see the article). In this connection, the papers of the Festschrift directly relate to nearly all of these hot topics of modern condensed matter physics.



Professor Leonid V. Keldysh in his office, P. N. Lebedev Physical Institute, Russian Academy of Sciences, Moscow, 2006.

Apart from the first recollection paper by Elias Burstein, the second article on the "Physical Minimum" by Vitalii Ginzburg, and the last two review papers by the Editors, the articles are alphabetically ordered following the name of the first author.

The paper by V. M. Agranovich deals with the physics of conceptually new hybrid organic–inorganic semiconductor nanostructures. The resonant coupling between the Frenkel and Wannier–Mott exciton states in two different materials of the nanostructure can lead to a fast and efficient noncontact and nonradiative energy transfer. Furthermore, the exciton-mediated nonlinearities are strongly enhanced in these artificial structures. The author also discusses a new family of light-emitting devices based on hybrid organic–inorganic semiconductor nanostructures.

The use of surface acoustic waves (SAWs) in an electron-spin based quantum state processor is reviewed in the paper by C. H. W. Barnes and M. Pepper. The authors discuss a SAW-induced electric current of discrete single or controllable numbers of electrons which can interact and become entangled. Variable g-factor materials are proposed as a means of applying electrical control to single-qubit rotation and as a form of optical input and readout. The processing scheme can be used as a component in a quantum communications network.

D. M. Basko, I. L. Aleiner and B. L. Altshuler review their recent work on the nonzero-temperature metal–insulator transition which occurs in a system of weakly interacting electrons in the presence of a disorder potential strong enough to localize all the single-particle states. The authors show that for the short-range weakly interacting electrons, the many-body localization transition is well-defined to all orders of perturbation theory.

In the paper by E. Burstein, the author overviews electric-field-induced Raman scattering of the light field which resonates with the interband transition in a semiconductor. The role played by the Franz–Keldysh effect in surface space-charge electric-field-induced Raman scattering is particularly emphasized. A strong enhancement of the efficiency of "forbidden" exciton-mediated Raman scattering by applying a static electric field, the effect predicted and observed by the author and his colleagues, is also discussed.

L. V. Butov reviews his recent achievements in experimental realization of a cold but still dense gas of long-lived indirect excitons in GaAs-based coupled quantum well structures. The unusual dynamics (photoluminescence jump) and pattern formation (inner and external rings, as well as fragmentation of the external ring in circular-shaped spots), which were detected in time-resolved and spatially-resolved photoluminescence associated with indirect excitons, are described in detail.

The fractional quantum Hall effect and composite fermions in a two-dimensional electron system are analyzed in the paper by I. V. Kukushkin, J. H. Smet and K. von Klitzing. The underlying picture of a composite fermion, a quasiparticle consisting of one electron and two magnetic flux quanta, is detailed and qualitatively illustrated. The authors also discuss detection of the composite fermions in cryogenic transport and optical experiments.

In connection with cavity quantum electrodynamics, the optical properties of a few-mode semiconductor microcavity with embedded quantum dots are reviewed in the article by V. D. Kulakovskii and A. Forchel. The authors discuss both the weak (Purcell effect) and strong (polariton effect) coupling limits of the "microcavity single-mode light – quantum dot" interaction. The experimental realization of the strong coupling limit is illustrated for a high-quality (high-Q) GaAs-based pillar microcavity.

M. Kuwata-Gonokami overviews mid-infrared pump–probe spectroscopy which is applied to visualize picosecond dynamics of excitons and electron–hole ensembles in bulk CuCl and Cu_2O. For CuCl, the author describes his experimental results on the Mott transition from the excitonic phase to an electron–hole plasma. The observed spatial segregation of the two phases is also discussed. For Cu_2O, the measurements of the infrared Lyman series associated with orthoexcitons are reviewed, and an effective generation of paraexcitons through scattering of cold orthoexcitons is proposed.

In the review paper by P. B. Littlewood, a collective coherent ground state in "exciton-like" many-body systems (excitons, microcavity polaritons, quantum Hall bilayers, dimer spin systems, ultracold atomic fermi gases, etc.) is discussed in terms of Bose–Einstein condensation. Both cases, the high-density limit (BCS limit) and low-density limit (BEC limit), are described in a unified way. Finally, the author outlines the decoherence effects which are relevant to a thermodynamically open system such as short-lived microcavity polaritons.

Inelastic light scattering by low-lying excitations of two-dimensional quantum Hall fluids in semiconductor nanostructures at very low temperatures and large magnetic fields is reviewed in the contribution by V. Pellegrini and A. Pinczuk. The authors show that the optical methods yield unique access to the elementary excitations of a many-electron system in the quantum Hall regime and discuss their measurements of charge and spin excitations for various values of the filling factor ν.

L. P. Pitaevskii outlines the Lifshitz equation, which describes the interaction potential of an atom with the surface of a bulk dielectric medium, and shows how to obtain this equation in a much simpler and more straightforward way comparing to the original derivation by E. M. Lifshitz. The key methodological point of the proposed approach is to neglect the retardation effects and evaluate the Green function of the longitudinal light field. Finally, the author recollects his first meeting with Leonid Keldysh which took place in 1958.

In the paper by E. I. Rashba, the author reviews the fundamentals of semiconductor spintronics and recent developments in this field. In order to manipulate and control the electron spin, such methods as electrical spin orientation, optical and electrical spin injection are discussed. Furthermore, the author outlines the spin interference phenomena, transport in media with spin–orbit coupling, and the spin Hall effect.

Metal–insulator transitions in disorder-free crystals are described in the paper by T. M. Rice. The author reviews excitonic insulators, electron–hole liquids and metal–insulator transitions due to band crossing. The realization of an exciton

(Bose–Einstein) condensate in the high-density limit is illustrated by experiments on a quantum Hall bilayer. In the second part of the paper, the Mott transition from a metal to a Coulomb localized insulator is discussed in terms of the one-band Hubbard model.

The chapter written by N. N. Sibeldin reviews an electron–hole liquid. This very interesting phase, observed mainly in bulk indirect semiconductors, Ge and Si, was thoroughly investigated in the late 1960s–mid-1980s. The first discovery of the electron–hole liquid with the subsequent study of its many unusual properties were initiated by L. V. Keldysh.

V. B. Timofeev overviews the attempts to realize Bose–Einstein condensation of excitons in bulk semiconductors and semiconductor nanostructures, with emphasis on indirect excitons in GaAs/AlGaAs coupled double quantum wells. The author details his recent experiments with indirect excitons confined in a circular electric-field-induced in-plane trap. The observed spatially-ordered patterns in the photoluminescence signal and large coherence length are interpreted in terms of Bose–Einstein condensation of indirect excitons.

The review paper by R. Zimmermann deals with Bose–Einstein condensation of excitons. After a historical survey of the search for Bose–Einstein condensation of excitons, the author concentrates on long-lived indirect excitons in coupled quantum wells: Bose–Einstein condensation of noninteracting bosons in a two-dimensional parabolic trap is outlined, and the ground-state wavefunction of indirect excitons is discussed in detail. Finally, the author presents his resent theoretical results on the concentration-dependent blue-shift and broadening of the photoluminescence line associated with indirect excitons.

A. L. Ivanov reviews the recently proposed concept of resonant acousto-optics, when interaction between the light and acoustic waves is mediated and strongly enhanced by the polarization field associated with either excitons (i.e., visible spectral band) or TO-phonons (THz band). For resonant acousto-optics, both dominant interactions, the polarization-light coupling (polariton effect) and the interaction of the polarization wave with the acoustically-induced grating, are treated nonperturbatively (strong coupling regime) and on an equal basis.

S. G. Tikhodeev and H. Ueba overview the recent results on inelastic electron tunneling spectroscopy of a single absorbed molecule. The authors analyze an adsorbate-induced resonance coupled to the molecular vibration. A theoretical description of inelastic electron tunneling is given in terms of the nonequilibrium Keldysh diagram technique.

On behalf of all contributors to the volume, we sincerely wish Professor Leonid Keldysh new research results, good health, optimism and vitality!