Activity Report of the CFBS-Project - Application for Extension

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Chapter 1

The Project and its Members

With the continuing progress in nanostructure technology the border-lines between the physics of condensed matter, and few-body quantum systems (as we have first encountered them in atomic and nuclear physics) are crossed. Much of the many-body physics that was developed for the understanding of atoms or nuclei, can be applied to describe quantum dots, wires, or clusters. In turn, much fundamental insight has been gained by studying low-dimensional quantum structures as they have become experimentally feasible. The physics of finite quantum systems, i.e. a few fermions or bosons in a trap, continues to keep ready many surprises.

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Chapter 2

Activities of the Nordic Project on Confined Fermion and Boson Systems 2001

2.1 Activities of the Groups

Here the activities of the participating groups in the year 2001 are reported.

2.1.1 Jari Kinaret, Göteborg

I am involved in three projects, two of which are active and the third in a planning stage.

1. Effects of Coulomb interactions on supercurrent in SNS structures. Together with Klas Engström (Chalmers) and Martti Puska and Henri Saarikoski (Helsinki) we have investigated the effects of Coulomb interactions on the supercurrent through a quantum dot connected to superconducting reservoirs. We are employing a combination of DFT and sparse matrix diagonalization techniques, and have found that the supercurrent through a quantum dot may be controlled electro- statically. We have completed the first stage on purely one-dimensional structures (submitted to PRL) and are presently extending the analysis to two-dimensional devices.

2. Nanoelectromechanics of carbon nanotube cantilevers. Together with Susanne Viefers and Torgny Johansson (both Chalmers) we are investigating a nanoelectromechanical device, a nanorelay, in which a flexible conducting nanotube forms an electric contact between source and drain electrodes. The tube can be bent by a capacitive force controlled by a gate electrode, thereby forming a nanoelectromechanical switch. At present, we are analyzing the dynamics of a two-terminal version without a gate electrode

modeling the nanotube alternatively as a Luttinger liquid or as a classical transmission line, and during the next year we intend to extend the analysis to the three terminal device. This work has a close connection to experiments that are being planned at Chalmers.

3. Together with Jussi Timonen (Jyväskylä) and Ilya Krive (Chalmers/Kharkov) we are planning to investigate the electric properties of random networks of carbon nanotubes, and study the crossover from a one-dimensional Luttinger-type behavior to the two-dimensional Fermi-liquid behavior. At present, we are at the initial stages, and have recently involved a young graduate student, Jae Uk Kim (Chalmers) in this project.

2.1.2 Yuri Galperin, Oslo University

Really confined systems

- *Giant Nonlinear Absorption by an Ensemble of Metallic Grains*,
  Y. M. Galperin and K. A. Chao,
  Foundations of Physics, **30** 2135-2150 (2000).

  We have investigated the nonlinear low-frequency microwave absorption of an ensemble of small metallic grains. Earlier Zhou et al. [Phys. Rev. Lett. 77, 1958 (1996)] have proved that linear absorption by such a system is due to a mesoscopic relaxation mechanism for which important contribution is from the grains with small level spacings between the ground state and the first excited state. In the paper we have shown further that such grains are anomalously sensitive to the field amplitude and the distribution of level spacings. Since such a behavior depends on external magnetic field, we expect the appearance of a giant nonlinear magnetoresistance, as well as a very strong temperature dependence of the nonlinear microwave conductivity.

- *Coherent transfer of Cooper pairs by a movable grain*,
  L. Y. Gorelik, A. Isacsson, Y. M. Galperin, R. I. Shekhter, M. Jonson,
  Nature **411**, 454-457 (2001).

  We demonstrate theoretically that a movable Cooper-pair box oscillating periodically between two superconducting electrodes can serve as a mediator of Josephson coupling leading to coherent transfer of Cooper pairs between the electrodes. Both the magnitude and direction of the Josephson current can be controlled by externally applied electromagnetic fields. We think that the system under consideration can serve as an element for a quantum computer.

Quantum point contacts and channels

- *Acoustoelectric effect in a finite-length ballistic quantum channel*,
  O. Entin-Wohlman, Y. Levinson, and Y. M. Galperin,
  Phys. Rev. B **62**, 7283 (2000)

  The dc current induced by a coherent surface acoustic wave (SAW) of wave vector q in a ballistic channel of length L is calculated. The current contains two contributions, even and odd in q. The even current exists only in a asymmetric channel, when the electron reflection coefficients r1 and r2, at both channel ends, are different. The direction of the even current does not depend on the direction of the SAW propagation, but is reversed upon interchanging r1 and r2. The direction of the odd current is correlated with the direction of the SAW propagation, but is insensitive to the interchange of r1 and r2. It is shown that both contributions to the current are nonzero only when the electron reflection coefficients at the channel ends are energy dependent. The current exhibits geometric oscillations as a function of qL. These oscillations are the hallmark of the coherence of the SAW and are completely washed out when the current is induced by a flux of noncoherent phonons. The results are compared with those obtained previously by different methods and under different assumptions.

- *Quantized acoustoelectric current in a finite-length ballistic quantum channel: The noise spectrum*
  Y. M. Galperin, O. Entin-Wohlman, and Y. Levinson
  Phys. Rev. B **62**, 7283-7288 (2000).

  Fluctuations in the acoustoelectric current, induced by a surface acoustic wave propagating along a ballistic quantum channel, are considered. We focus on the large-wave-amplitude case, in which it has been experimentally found that the current is quantized, and analyze the noise spectrum. A phenomenological description of the process, in terms of a random pulse sequence, is proposed. The important ingredients of this description are the probabilities pn for a surface acoustic wave well to capture n electrons. It is found that from the noise characteristics one can obtain these probabilities, and also estimate the typical length scales of the regions in which the electrons are trapped.

- *Impurity-induced dephasing of Andreev states*
  N. I. Lundin and Y. M. Galperin
  Phys. Rev. **63** (9), Article 094505 (2001)

  A study is presented concerning the influence of flicker noise in the junction transparency on coherent transport in Andreev states. The amount of dephasing is estimated for a microwave-activated quantum interferometer.

Possibilities of experimentally investigating the coupling between a superconducting quantum point contact and its electromagnetic environment are discussed.

2.1.3 Susanne Viefers, Göteborg

Exclusion statistics in a 2D trapped Bose gas

We [1] have shown that a *two-dimensional* Bose gas with repulsive delta-function interaction obeys Haldane's exclusion statistics (a generalization of the Pauli principle, intermediate between Bose-Einstein and Fermi-Dirac statistics) and is equivalent to an ideal (non-interacting) exclusion statistics gas. This is particularly interesting as all previous established examples of exclusion statistics were in 1D, and because such 2D Bose gases are experimentally realizable with present trapping techniques.
[1] T.H. Hansson, J.M. Leinaas and S. Viefers, Phys. Rev. Lett. **86**, 2930 (2001); S. Viefers, T.H. Hansson and J.M. Leinaas, J. Phys. **B**, in press.

Carbon nanotubes and nanoelectromechanical systems

We [2] study the physical properties of a so-called *nanorelay*: A nanotube with one end fixed on a step in the substrate, the other free to vibrate, and with the possibility of electron tunneling between the free end and a contact in the underneath substrate. This is an example of a *nanoelectromechanical system* (NEMS), in which one takes advantage of the interplay between electronic and mechanic degrees of freedom at nano-scale. Such systems may play an important role in future electronics.
[2] Work in progress, with J. Kinaret, T. Johansson and T.H. Hansson

Many-body spectrum and particle localization in quantum dots and finite rotating bose condensates

The yrast spectra (i.e. the lowest states for a given total angular momentum) of quantum dots in strong magnetic fields, have been studied in terms of exact numerical diagonalization and analytic trial wave functions. We argue that certain features (cusps) in the many-body spectrum can be understood in terms of particle localization due to the strong field. A new class of trial wavefunctions supports the picture of the electrons being localized in Wigner molecule-like states consisting of consecutive rings of electrons, with low-lying excitations corresponding to rigid rotation of the outer ring of electrons. The geometry of the Wigner molecule is independent of interparticle interactions and the statistics of the particles.
[3] M. Manninen, S.Viefers, M. Koskinen and S.M. Reimann, submitted to Phys. Rev. **B**.

2.1.4 Matti Manninen, Jyväskylä

Main research activities:

- Ab initio computations of the electronic structure of quantum dots in order to understand electron localization
- Study of model Hamiltonians for explaining the exact many-body spectrum and for studying finite temperature effects
- Electron-electron and electron-hole correlations in vertical double dots
- Development of density functional methods for computing quantum dot (and antidot) lattices

Publications:

- M. Koskinen, M. Manninen, B.R. Mottelson, S.M. Reimann, Rotational and vibrational spectra of quantum rings, Phys. Rev. B 65, 205323 (2001). (collaboration: Jyväskylä - Nordita)
- M. Manninen, M. Koskinen, S.M. Reimann, and B. Mottelson, Magnetic properties of quantum dots and rings, Eur. Phys. J. D (in press). (collaboration: Jyväskylä - Lund - Nordita)
- M. Manninen, S. Viefers, M. Koskinen, and S.M. Reimann, Many-body spectrum and particle localization in quantum dots and finite rotating bose condensates, Phys. Rev. B (submitted). (collaboration: Jyväskylä - Chalmers - Lund)
- S.M. Reimann and M. Manninen, Shell structure in artificial atoms, Rev. Mod. Phys. (submitted). (collaboration: Jyväskylä - Lund)

2.1.5 Stephanie Reimann, LTH Lund

Much of my work focused on nanostructured quantal systems and was performed in close collaboration with the group of M. Manninen at the University of Jyväskylä. I refer to the description of results and future plans that was provided above by M. Manninen.
This collaboration also included the preparation of a review article as an invited contribution to Rev. Mod. Phys., which was submitted in July 2000.

In addition to my work on the electronic structure of quantum dots and phenomena related to spin effects in nanostructured condensed matter systems, I was involved in studies on a weakly interacting Bose-Einstein condensate under rotation. This work was performed in collaboration with Ben Mottelson and G. Kavoulakis who in September joined the group in Lund.

The publications originating from this collaboration are listed below.

- Exact versus mean-field solutions in a rotating Bose-Einstein condensate
  G. Kavoulakis, B. Mottelson and S.M. Reimann
  submitted to Phys. Rev. A
  (e-print http://arXiv.org/abs/cond-mat/0109329)

- Low-lying excitations of a trapped rotating Bose-Einstein condensate
  G. Kavoulakis, B. Mottelson and S.M. Reimann
  Phys. Rev. A 63, 055602 (2001)

- Weakly Interacting Bose-Einstein Condensates Under Rotation:
  Mean-field versus Exact Solutions
  A. Jackson, G. Kavoulakis, B. Mottelson and S.M. Reimann
  Phys. Rev. Lett. 86, 945 (2001)

The planned research activities in 2002 will be mainly concerned with

- improvements of the local density approximation in two dimensions (in collaboration with M. Seidl and M. Brack, Regensburg University)

- the electronic structure of single quantum dots and their coupling to quantum dot molecules and lattices (in collaboration with the Jyväskylä group)

- double-layer quantum dots with electrons and holes (in collaboration with the Jyväskylä group and G. Kavoulakis)

- excitons in quantum wells and bulk semiconductors (in collaboration with G. Kavoulakis)

- questions related to the above mentioned studies of rotating Bose-Einstein condensates (in collaboration with B. Mottelson and G. Kavoulakis)

First activities to initiate a closer collaboration between NORDITA and LTH Lund were followed in the framework of the NORDITA workshop held in August, which we describe below.
To encourage a closer interaction, a series of common seminars, mostly taking place at LTH is currently organized, where the particular aim is to increase the interaction with the NORDITA fellows. (A further description of such activities is described in my application for a prolongation of the 'corresponding fellow'-ship which I will submit to Nordita in connection with this Nordic project.)

2.1.6 Georgios M. Kavoulakis, LTH Lund

In the recent months I have been involved in two different projects:

- The physics of a trapped, weakly interacting Bose-Einstein condensate, and more precisely its behavior under rotation. In this project I have collaborated with A. D. Jackson, B. Mottelson C. J. Pethick, and S. M. Reimann. Our (recent) studies on this problem can be seen in S. M. Reimann's section.

- Optical and transport properties of excitons in semiconductors, and also the Bose-Einstein condensation of excitons in Cu_2O. In this project I have collaborated with A. D. Jackson and K. Johnsen.

Here are the relevant preprints:

• *"Propagation of exciton pulses in semiconductors"*, A. D. Jackson and G. M. Kavoulakis (e-print http://arXiv.org/abs/cond-mat/0107103).

• *"Bose-Einstein condensation of excitons in Cu_2O"*, G. M. Kavoulakis, (e-print http://arXiv.org/abs/cond-mat/0012386).

• *"Probing Bose-Einstein Condensation of Excitons with Electromagnetic Radiation"*, K. Johnsen and G. M. Kavoulakis, Phys. Rev. Lett. **86**, 858 (2001).

2.1.7 Viðar Guðmundsson, Reykjavík

In the year 2001 the research has been focused on three main topics within the scope of the project. The coworkers are listed in the publication list.

- How is the FIR-absorption spectrum of a quantum dot changed due to the presence of other dots, or by the interaction with neighboring dots in an array?

- How does the FIR-absorption of a single quantum dot change when the radiation is very intense? What happens in this nonlinear regime?

- How can a quantum dot formed at the tip a tunneling microscope be used to explore the properties of a two-dimensional electron system?

- Non-locality of the exchange interaction probed by scanning tunneling spectroscopy, M. Morgenstern, V. Gudmundsson, R. Dombrowski Chr. Wittneven, and R. Wiesendanger, *Phys. Rev. B***63**, 201301(R) (2001).

- Far-Infrared Excitations below the Kohn Mode: Internal Motion in a Quantum Dot, Roman Krahne, Vidar Gudmundsson, Christian Heyn, and Detlef Heitmann, *Phys. Rev. B***63**, 195303 (2001).

- Excitations below the Kohn Mode; FIR-Absorption in Quantum Dots, Vidar Gudmundsson, Roman Krahne, Christian Heyn, and Detlef Heitmann, *Physica Scripta*, submitted (2001).
- Inter-Dot Interaction in an Array of Elliptical Quantum Dots, Roman Krahne, Vidar Gudmundsson, Christian Heyn, and Detlef Heitmann, *Physica E*, submitted (2001).
- Hartree-Fock dynamics in highly excited quantum dots, Antonio Puente, Llorenç Serra, and Vidar Gudmundsson *Phys. Rev. B*, in print (2001).
- From single dots to arrays, Vidar Gudmundsson, Roman Krahne, Detlef Heitmann, *North-Holland/Elsevier*, in preparation (2001).

2.2 Project Meeting in Copenhagen August 30 - 31 2001

2.2.1 Scientific Part

In the year 2000 the members of the CFBS-Project met in Trento together with several researchers from different Universities and Institutes all over the world. The workshop had been organized by Stephanie Reimann, Ben Mottelson, Poul Erik Lindelof, Hans Weidenmüller and Vidar Gudmundsson. In light of the success of this meeting we decided to invite researcher outside the project to enrich the meeting in Copenhagen 2001.
The project meeting 2001 was organized for 3 days with the following scientific program the first two days. In order to give the project members insight into what is happening in the field in the Øresund region we invited several speakers from the Copenhagen and Lund area. We also included researchers from Hamburg and Berlin to follow up on new developments in the field. As could be expected we did hear of new things happening at the new Nanolab in the Ørsted Institute, Lund University, The University of Hamburg, and the Technical University in Berlin. We also hope that researchers from these institutes learned something about our activities. Certainly, many new links were created.

Thursday, August 30

10:00 - 10:10 : Opening: Vidar Gudmundsson.

10:10 - 10:50 : Spin injection in hybrid ferromagnetic/2DEG devices
Can-Ming Hu, Universität Hamburg.

10:50 - 11:20 : Quantum-Monte-Carlo for quantum dots
Wolfgang Häusler, Universität Freiburg.

11:20 - 11:50 : One- and two-phonon capture processes in quantum dots
Ingibjörg Magnúsdóttir, COM, DTU, Copenhagen.

12:30 - 14:00 : Lunch break, NBI-cantina.

14:00 - 14:30 : Quantum-Cascade-Laser
Andreas Wacker, Technische Universität Berlin.

14:30 - 15:00 : Density functional theory from the limits of strong and weak interaction: The 2D electron gas
Michael Seidl, Universität Regensburg.

15:30 - 16:00 : Coffee break.

16:00 - 16:45 : Electron transport in molecular electronic devices
Kurt Stokbro, MIC-DTU, Copenhagen

16:45 - 17:30 : Fabrication of zero- and one-dimensional structures and their use in nanoelectronic devices
Lars Samuelson, University of Lund, Lund.

17:30 - 18:00 : Electronic properties of in situ grown single walled carbon nanotubes
Jørn Borggren, Ørsted Laboratory, Copenhagen.

Friday, August 31

10:00 - 10:30 : Influence of Electron-Electron Interactions on Supercurrent in SNS Structures
Jari Kinaret, Chalmers University, Göteborg.

10:30 - 11:00 : Bose-Einstein condensates under rotation
Georgios Kavoulakis, KTH, Stockholm.

11:00 - 11:30 : Many-body spectrum and particle localization in quantum dots and rotating bose condensates
Matti Manninen, University of Jyvaskylä.

11:30 - 12:15 : Carbon nanotubes and nanoelectromechanical systems
Susanne Viefers, Chalmers University, Göteborg.

12:30 - 14:00 : Lunch break, NBI-cantina.

14:00 - 14:30 : Charged clusters in the electron-hole liquid
Mikko Saarela, Oulu University, Oulu.

14:30 - 15:00 : Electron dynamics in highly excited quantum dots
Vidar Gudmundsson, University of Iceland, Reykjavík.

15:00 - 15:30 : Features of Dephasing and AC Oscillations in a Open Aharanov-Bohm Ring
Zhongshui Ma, University of Lund, Lund.

15:30 - 16:00 : Coffee break.

16:00 - 16:30 : Optoelectric Spin Injection without Magnetic Elements
Kung-An Chao, University of Lund, Lund.

16:30 - 17:00 : Propagation of exciton pulses in semiconductors
Georgios Kavoulakis, KTH, Stockholm.

2.2.2 Finances of the Project Meeting

The finances of the project meeting in Copenhagen were as is shown in the table supplied to us by Ellen Pedersen.

Rejse- og dagpenge:

Koung-An Chao, Lund	1.330.00
Zhongshui Ma, Lund	1.330.00
Michael Seidl, Regensburg	8.076.00
Mikko Saarela, Oulu	6.156.00
Susanne Viefers, Göteborg	5.064.00
Vidar Gudmundsson, Reykjavik	9.502.48
G. Kavoulakis, Stockholm	3.664.50
Daniela Pfannkuche, Hamburg	7.149.50
Wolfgang Häusler, Freiburg	5.179.00
Jari Kinaret, Göteborg	1.935.00
Stephanie Reimann, Lund	565.00
Andreas Wacker, Berlin	2.538.00
Can-Ming Hu, Hamburg	2.308.00
Matti Manninen, Jyväskylä	2.735.00
Ialt	57.532.48

Hotel + diverse

Hotel 9 Små Hjem (4 gæster)	6.510.00
Restaurant Langelinie	5.750.00
NBI-kantinen, kaffe + kage	775.00
Ialt	13.035.00

Udgifter ialt	70.567.48

Some money had been used earlier in the year, but the total sum for the expenditures in the year 2001 is less than the DKK 100.000,- awarded by NORDITA.

Chapter 3

Application for the Extension of the Project for the 3rd year

3.1 Plan for 2002:

As before, we want to encourage exchanges between the participating research groups. Most of the research projects already mentioned in the Activity Report for 2001 are continuing. And clearly the Nordic Project has led to cooperations that will go beyond the maximum 3 years it could be extended to. By the practice of inviting a limited number of researchers outside the project to our meetings we have successfully extended the scope of the project in terms of participating groups, specially with connection with experiments.
In addition, we would like to organize a project meeting in connection with the summer school and workshop in Jyväskylä:
The University of Jyväskylä will arrange in August 2002 an International Summer School on nano sciences. The school will have two courses on nanophysics. In connection to the summer school we will arrange an international workshop on nanophysics.

Workshop on "nanophysics"

Idea : Bring together physicists working on finite quantum systems like quantum dots and clusters and related areas in chemistry and biology.

Place : Jyväskylä

Time : August 2002, length 5 days

Size : 50 participants

Format : 25-30 speakers, by invitation poster sessions, no proceedings, young researchers encouraged to participate,

Budget :

Invited speakers : 24×5000 FIM = 120.000 FIM (partial support only).

Others : 20×2000 FIM = 40.000 FIM

Social program 50×300 FIM = 15.000 FIM (maybe nominal participation fee is needed).

Organization : (Secretarial help etc) 5000 FIM

Total : 180.000 FIM = about 225.000 DKR

Facilities : (University will provide the meeting room)

Sponsors : NORDITA conference support (120.000 DKK), Academy of Finland (20.000 DKK), University of Jyväskylä (5.000 DKK). The Nordic Project would support its own members to participate in the meeting together with a subsequent or concurrent project meeting (80.000 DKK).