annual report 2003

JYFL

DEPARTMENT OF PHYSICS • UNIVERSITY OF JYVÄSKYLÄ

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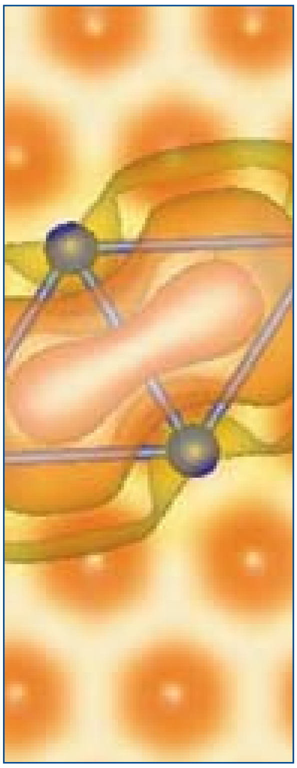

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annual report
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DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

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Contents

Department of Physics

Matti Leino

The Department of Physics (JYFL) with its 560 students and 155 employees is one of the largest departments of the University of Jyväskylä. A summary of the JYFL personnel is given in the table on the next page. The number of researchers in the table also includes the graduate students (~60).

During the year, several staff members with a long career in the Physics Department retired. Professor Esko Liukkonen was one of the leading figures in setting up and running both the old cyclotron at Nisulankatu and the present K = 130 MeV machine. Docent Pekka Suominen shifted his career during the years from experimental nuclear physics to applied and environmental issues as well as teaching. Laboratory technician Paavo Onkila was known for a very high level of quality in his work.

One of the more recently appointed staff members, professor Jyrki Räisänen, left the Department to return to his alma mater, the University of Helsinki. During his five-year-stay at JYFL, professor Räisänen started a successful and many-sided programme in fundamental and applied research in materials science. The position he left behind is currently in the final stages of being filled. Dr. Markus Ahlskog was appointed professor in nanophysics and has recently joined our staff. Together with professor Päivi Törmä, professor Matti Manninen and altogether some 40 staff members, he is facing the challenge of moving to the new Nanoscience building later this year.

Teaching

In teaching the year was very successful. The numbers of MSc and PhD degrees awarded in physics were 41 and 11, respectively. The Department started its first year as one of the high-quality education units in Finland. JYFL participates in several national graduate schools and coordinates the Graduate School in Particle and Nuclear Physics. Four foreign students from three to twelve months visited the Accelerator Laboratory under the programme of a Marie Curie Host Training Site. The importance of developing and improving the quality of teaching is fully recognized and more resources have been devoted to this area. The Department took an

Some statistical data in 2003

Personnel	155	(58)
- professors	12	(12)
- lecturers	4	(4)
- senior assistants	7	(8)
- assistants	4	(5)
- researchers and research assistants	98	(5)
- technicians	25	(20)
- administration	5	(4)
( ) = permanent posts		
Undergraduate students	500	
of which new students	122	
Graduate students	60	
MSc degrees	41	
PhLic degrees	4	
PhD degrees	11	
Credits (national)	6170	
Median time to complete MSc (years)	5,3	
Number of foreign vistors	~250	
Visits abroad	~200	
Peer reviewed publications	127	
Invited talks	48	
Other talks	53	
Posters	65	
Funding (million €)	8,6	
* University budget (excl. premises)	4,3	
* External funding	4,3	
- Academy of Finland	1,7	
- Technology Development Centre	0,4	
- International programmes	0,7	
- ESR, EAKR	0,3	
- HIP, HUT etc.	0,5	
- Contract research	0,4	
- Others	0,3	

active position regarding the University's proposed plan of controlling the quality of teaching. Our view was that too much emphasis was placed on relatively unfruitful bureaucracy while ongoing successful projects in several departments e.g. in the Faculty of Mathematics and Science were largely ignored.

Research

The year 2003 was for most of the department the fourth year as the Finnish Centre of Excellence in Nuclear and Materials Physics. Planning has already started to participate in the next round of proposals later this year for the renewal of the status. The accelerator laboratory continued as an EU Major Research Infrastructure having approximately 200 outside users. JYFL groups participate in about 15 international research projects, in three of them as a coordinator.

The JYFL activities in the CERN-ALICE and CERN-ISOLDE projects are carried out within the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP). The theoretical research on ultrarelativistic heavy ion collisions at JYFL is a part of the Theoretical Physics Programme of HIP.

In nanophysics and nanotechnology, the research focuses on physics in the nanoscale as well as on experiments and theory of the electronic and thermal properties of micron and submicron size structures. Thermal properties of insulating nanostructures and the coupling between electronic and lattice (phonons) degrees of freedom is one key field, as is quantum coherence in small Josephson junctions, studied for finding out whether these systems can be used as elements of a quantum computer. Lithography based on electron beam and atomic force microscopy are used in the fabrication of nanostructures.

In nanoelectronics and nanotechnology, the focus is in multidisciplinary nanoscience projects, for instance research on electrical conductivity of macromolecules such as DNA. Bionanosensors are developed in collaboration with industry and other groups of the NanoScience Center. The theory research includes superfluid Fermion gases, photonic crystals and quantum information.

Research in soft condensed matter and statistical physics deals with problems like fracture of brittle materials, fluid flow in porous structures and particulate suspension flows, and propagation of interfaces. This research includes experiments as well as extensive ab initio numerical simulations. Recently much effort has been given to construction of a novel device for tomographic imaging based on diffuse scattering of light, and to tomographic imaging of paper like materials with ordinary x-rays or syncrothron radiation. Applications are typically in paper physics, paper machine technology and bone research.

The theory of atomic clusters and their relations to other areas (nuclear physics and semiconductor nanostructures) are studied in collaboration with the experimental research group in nanotechnology. The main research emphasis is in the electronic and magnetic structure of metal clusters on surfaces, quantum dots, point contacts and nanowires.

In 2003, the total operating time of the JYFL cyclotron was again nearly 7000 hours. More than 2500 hours of beam time were devoted to the first joint-European JUROGAM campaign. The JUROGAM array combined with the RITU separator and the focal plane GREAT spectrometer forms the most efficient spectrometer system in the world for structure studies of heavy proton drip-line nuclei and trans-fermium nuclei in the tagging experiments. At the IGISOL facility, mass measurements with the purification ion-trap revealed an interesting behaviour of neutron separation energies in the shape transitional neutron-rich Zr isotopes. Test measurements with the high-resolution trap have been very promising.

In the semiconductor industry and nanotechnology there is an increasing interest in the use of ion beams. The goal of accelerator based applied research is to improve the understanding of mechanisms in ion beam modification of materials and microelectronics. These studies have direct impact on the development of radiation hard components and solar cells, e.g. for space technology, and new processing methods for micro- and nanotechnology.

The nuclear theory group develops microscopic nuclear models and applies them to nuclear spectroscopy, and to description of rare weak decays important for the physics of weak interactions, neutrinos and dark matter.

In high-energy physics the theoretical research has widened from the physics of quark-gluon plasma and ultra-relativistic heavy ion collisions to studies in neutrino physics, particle astrophysics and cosmology.

Center of Excellence in Nuclear and Condensed Matter Physics

Juha Äystö

Research areas and project leaders

Nuclear physics and particle accelerators
(Prof. Rauno Julin, Prof. Matti Leino,
Prof. Esko Liukkonen, Doc. Pauli Heikkinen,
Prof. Jouni Suhonen, Prof. Juha Äystö)

Ion beam physics and applications
(Prof. Jyrki Räisänen, Doc. Ari Virtanen)

Condensed matter physics and nanotechnology
(Prof. Matti Manninen, Dr. Ilari Maasilta,
Prof. Jussi Timonen)

Centre of Excellence in Nuclear and Condensed Matter Physics carries out research on three subject areas which form a compact programme focusing on different aspects of the basic structure of matter and its constituents. The activities comprise about 80 % of the research effort of the Department of Physics (JYFL) and is funded under the contract between the Academy of Finland and the University of Jyväskylä. The present funding period extends until the end of 2005. The research teams have enjoyed a very active and productive year. The number of refereed publications was 105 and the number of invited talks in international conferences was 33. The graduate and undergraduate students of the CoE form an important fraction of its work force. This is exemplified by 11 PhD and 3 Phil. Lic. degrees awarded in 2003.

One part of research comprises experimental and theoretical nuclear physics where the experimental part is carried out at the JYFL Accelerator Laboratory. The second part consists of applied research accompanied by a research programme on ion beam – matter interactions. The third part concerns theoretical and experimental condensed matter physics where the experimental part is mainly carried out at the JYFL Laboratory for Nanotechnology. More detailed descriptions of the scientific activities of the CoE are given in appropriate sections of this Annual Report.

Nuclear and accelerator physics at the CoE is a composition of different themes in experimental and theoretical nuclear physics as well as accelerator physics and technology. The internationally operating accelerator laboratory is supported as a research infrastructure by the EU for providing access to outside users. The main theme of research is the study of structure of exotic and superheavy nuclei far from the valley of stability. There are many links to the materials science research and to applied research in industry, space technology and medicine. The laboratory has recently been recognised by the European Space Agency as an official radiation test facility for space devices and electronics.

In the semiconductor industry there is an increasing interest in the use of MeV-ion implantations for device fabrication. The goal of our research is to improve the understanding of mechanisms in ion beam modification of selected microelectronics materials. The studies proposed have direct impact on the development of radiation hard (RadHard) components and solar cells as well as on space technology.

In nanotechnology, our research focuses on nanoelectronics, experiments and theory of the electronic properties of micron and submicron size structures and their fabrication. The laboratory is equipped with high quality lithography and processing facilities. The main research direction of the thermal nanostructure research is to understand energy flow mechanisms from electronic to phononic degrees of freedom and within the phonon system in restricted, low-dimensional geometries, and utilize this knowledge in the development of ultrasensitive thermal and radiation sensors (bolometry).

Atomic clusters are a nanoscopic state of matter in between small molecules and bulk matter, with a multitude of properties interesting for basic research and applied materials science. Atomic clusters and their relations to other areas (nuclear physics and semiconductor nanostructures) have been studied in Jyväskylä for about ten years. The main research emphasis is in the electronic and magnetic structure of metal clusters on surfaces, quantum dots, point contacts and nanowires.

Research on disordered materials is divided into three main areas. The first area is theory of rigidity and fracture of both brittle and ductile film like materials. Applications will typically be in paper physics. The second area is fluid flow in random porous structures and particulate suspension flows. The third area is propagation of interfaces in disordered, porous materials.

Research

Nuclear and accelerator based physics

Summary of the Accelerator Laboratory activities

Rauno Julin

In 2003, the total operating time of the cyclotron was close to 6900 hours, beam being on the target for a total of 5485. A total of 41 scheduled experiments were performed and the number of foreign collaborators visiting the laboratory was 180.

Technical development work of the accelerator facility focused on the further development of heavy ion beams and their intensities. These beams are important for the SEE tests of space electronics and studies of exotic nuclei produced with very low cross-sections.

At the IGISOL facility, mass measurements with the purification ion-trap revealed an interesting behaviour of neutron separation energies in the shape transitional neutron-rich Zr isotopes. Preliminary test measurements with the precision ion trap indicate that the system will be one of the world leading mass measurement instruments for radioactive beams. IGISOL had a shut down period of 5 months for a major upgrade with the goal of improving the beam quality and intensity. Development of new ultra-sensitive laser spectroscopic techniques to be employed at the upgraded IGISOL

Graduate students tuning the JUROGAM array.

facility is in progress. Experiments at the CERN-ISOLDE facility were carried out as a part of the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP).

More than 2500 hours of beam time was devoted to the tagging experiments of the first JUROGAM campaign carried out in collaboration between the JYFL gamma- and RITU groups and the groups from several foreign institutes. The JUROGAM array of 43 Ge detectors from EUROBALL and the UK-France-pool, combined with the RITU separator and the focal plane GREAT spectrometer form the most efficient spectrometer system in the world for structure studies of heavy proton drip-line nuclei and trans-fermium nuclei in the tagging experiments. Thirteen experiments were performed including coincidence studies of the triple-shape coexistence phenomenon in very light Pb isotopes and of trans-fermium nuclei.

The nuclear reaction group found evidence for Collinear Cluster Tripartition (CCT) – a new exotic decay mode in which a heavy nucleus, in this case ^{252}Cf, instead of fissioning disintegrates into 3 fragments of comparable mass determined by the magic clusters available to the system.

One of the novel applications at the JYFL accelerator facility was determination of diffusion properties of arsenic in intrinsic relaxed $Si_{1-x}Ge_x$ epi layers using the modified radiotracer method and radioactive ^{72}As and ^{73}As beams delivered by IGISOL and ISOLDE, respectively. This was the first time, that the full range of compositions from x=0 to x=1 has been covered for dopant diffusion studied in relaxed SiGe.

The research in the laboratory is a part of the Centre of Excellence in Nuclear and Materials Physics programme of JYFL. Until the end of January 2004 the JYFL accelerator was operated as one of the European Research Infrastructures in the IHP programme of the EU. JYFL groups are contractors of the FINUPHY activity of the IHP Infrastructures and the IHP-RTD projects EURISOL, ION CATCHER, NIPNET and EXOTAG, which is coordinated by a JYFL group. JYFL plays an active role in planning of the new Integrated Infrastructure Initiative for Nuclear Physics (EURONS) for the 6th framework programme of the EU.

JYFL coordinates the National Graduate School in Particle and Nuclear Physics (GRASPANP) and the accelerator laboratory has the status of a Marie Curie Training Site of the EU.

Accelerator facilities

Pauli Heikkinen

Since its inception in 1993 the cyclotron has been operated for over 64 000 hours, and during 1996-2003 the average running time has been 6740 hours/year. In 2003 the total operating time was 6918 hours, out of which the beam-on-target time was 5485 hours. The rest of the total time consisted of stand by time due to the user, beam tuning and developing. The most intensively used beam was protons for 30% of the total. The beam was mostly used for ^{123}I production and for proton induced fission at IGISOL. The second most popular beam was ^{48}Ca (11.7 %), which was delivered to the gas-filled recoil separator RITU. Altogether, almost 30 different isotopes were accelerated for experiments and beam development tests in 2003. The combined RITU- and gamma-group (performing experiments using the JUROGAM Ge array coupled to RITU) was the biggest user, taking up to 38.7 % of the beam time.

The main task of the ion source group during the year 2003 was to meet the larger intensity requirements for highly-charged heavy beams set by the RADEF facility. A TWTA transmitter was borrowed from Argonne National Laboratory for two-frequency tests with the JYFL 14 GHz ECRIS (Electron Cyclotron Resonance Ion Source) in order to see its effect on highly charged ions. As an example, the intensity of the Xe^{32+} ion beam improved by a factor of 7. In addition the beam current measurement system was improved, which increased the resolution by a factor of 10.

The sputtering method was studied in detail in order to improve the ion beams of titanium and molybdenum. Different Mo-compounds were also tested with the miniature oven. This work is still in progress.

During 2003 a new device for plasma potential measurements was developed. The device can be used to find new ECRIS plasma related information.

Most devices in the cyclotron laboratory are over 10 years old, and need either replacement or major maintenance. A comprehensive programme of maintenance and upgrading work of the water-cooling system was begun in the autumn of 2003. It is planned that some of the excess heat may be used to heat the indoor car park, which is under construction as a part of the nanoscience building.

Esko Liukkonen, professor -31.7.
Pauli Heikkinen, senior researcher
Hannu Koivisto, senior assistant
Sami Hahto, graduate student -30.9. (USA)
Pekka Suominen, graduate student
Olli Tarvainen, graduate student
Arto Lassila, laboratory engineer
Veikko Nieminen, laboratory engineer
Teuvo Poikolainen, laboratory engineer
Kimmo Ranttila, laboratory engineer
Juha Ärje, laboratory engineer
Jani Hyvönen, operator
Anssi Ikonen, operator
Hannu Leinonen, technician
Raimo Seppälä, technician

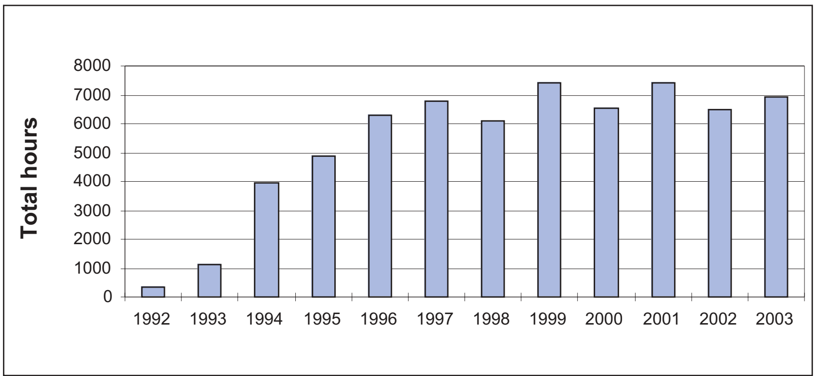

Fig. 1. Operation of the Jyväskylä cyclotron

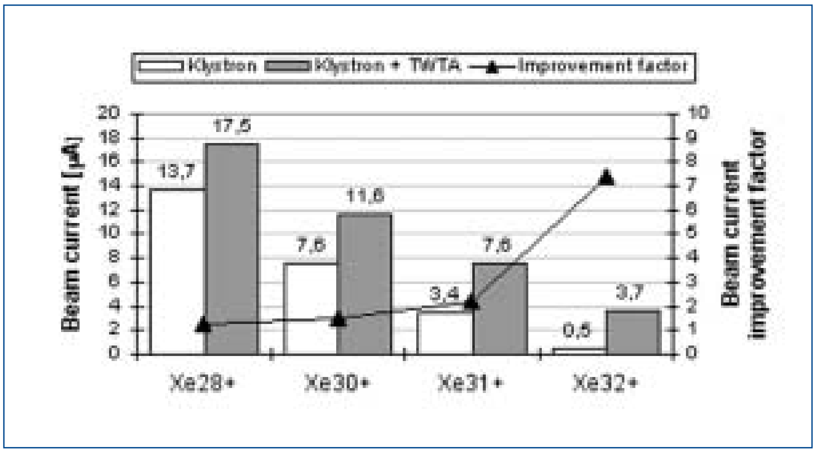

Fig. 2. Effect of TWTA on Xe-beams from the 14 GHz ECR.

Exotic nuclei and beams

Juha Äystö, Ari Jokinen and Heikki Penttilä

Juha Äystö, professor
Ari Jokinen, academy researcher
Heikki Penttilä, academy researcher
Stefan Kopecky, senior researcher
Jussi Huikari, postdoctoral researcher
Iain Moore, postdoctoral researcher 1.1.2004 -
Andrey Popov, postdoctoral researcher
Youbao Wang, postdoctoral researcher
Tommi Eronen, graduate student
Anu Kankainen, graduate student
Veli Kolhinen, graduate student -31.8.
Sami Rinta-Antila, graduate student
Bruce Marsh, Marie Curie Training Site student 1.12.-
Ulrike Hager, MSc student
Jani Hakala, MSc student
Pasi Karvonen, MSc student

Our activity in 2003 has continued along the well established path consisting of numerous activities in R&D on instrumentation as well as experiments at JYFL and ISOLDE, CERN. The work at ISOLDE is carried out within the Nuclear Matter Program of the Helsinki Institute of Physics. Major achievements have been the finishing of the IGISOL front-end upgrade after six months shutdown and the completion of the JYFLTRAP for precision mass measurements.

The first half of the year prior to upgrade was devoted to fission product studies that included yield measurements of heavy fission products, precise lifetime measurements on Ru and Pd isotopes, charge radii measurements on the neutron-rich cerium isotopes and direct mass measurements of Zr isotopes. The experiments performed in CERN at ISOLDE guaranteed smooth ongoing of the physics research program while the home laboratory was under construction.

Our team has been benefiting significantly from collaborations with several groups from Europe and US as well as EU-funded RTD networks. The latter include the Ion Catcher RTD project with aim to develop the experimental ion deceleration and gas stopping techniques, the NIPNET RTD project on novel instrumentation for precision experiments in traps as well as the EURISOL project aiming at the preliminary design of the second generation ISOL-based radioactive beam facility in Europe.

IGISOL upgrade

The upgrade project was launched after it became clear that the new ion beam manipulation devices, the ion cooler and the Penning trap system, would make the front end of the mass separator the weakest link of the facility. The goal of the upgrade was to improve the separator beam quality and increase its intensity by means of more effective pumping and better radiation shielding. This should allow for a full use of the high intensity light ion beams now available at the K130 cyclotron. All the valves and electrodes in the high radiation area were switched from manual to remote controlled, and the separator vacuum system was taken under computer control. Tentative yield tests gave three to sixfold overall improvement for light ion induced

Fig. 1. The new front end of IGISOL being installed in October 2003.

reactions. However, it is to be noted that the new IGISOL front end has yet been tested only with low primary beam intensities and ambitious extrapolations to high beam intensities should be avoided.

JYFLTRAP

During the first half of the year 2003 the purification-trap was used for studies of the mass surface of neutron rich zirconium isotopes. Zr isotopes are known to exhibit a structure change in the mass range between 98 and 100. Previously spectroscopic studies have investigated these properties, but so far no direct mass measurements had been performed for these nuclei. At IGISOL neutron-rich Zr isotopes are available with intensities of 4000 to 200 ion/s between ^{98}Zr and ^{104}Zr, respectively. In these measurements, the trapping scheme with the Penning trap was in total 450 ms, divided into 330 ms necessary for axial cooling, 15 ms for dipole excitation and 95 ms for quadrupole excitation. Typically the uncertainties for the masses derived from these measurements were a few 10's of keV. These new mass-values were used to deduce the two neutron separation energies shown in Fig. 2. It is expected that this function shows a smooth behaviour outside a region of shell closure. But in the case of the neutron-rich zirconium isotopes, this curve shows a strongly different behaviour. Some of the model calculations available in literature are able to predict the position of this discontinuity, but so far none is able to calculate its magnitude. Therefore, dedicated structure calculations are needed to explain the observed behaviour.

The second half of 2003, during the IGISOL upgrade, was used to characterize the precision trap. These experiments used a cross beam ion source mounted in front of the RFQ. In experiments with stable Xe ions it could be established that the transfer of the ions from the purification trap can be accomplished without any significant loss. In the precision trap a time-of-flight method is employed. This technique uses the conversion from radial into axial motion when the ions move out of the strong magnetic field. An initial pure magnetron motion can by quadrupole excitation be converted into cyclotron motion. This has a much higher radial energy leading to a shorter time-of-flight to a detector positioned outside the magnetic field. As the cyclotron frequency – and therefore the quadrupole excitation – is strongly mass dependent, a precise determination of the cyclotron frequency of an unknown ion will make possible precise mass determination of this ion. In Fig. 3 a TOF-scan for ^{132}Xe is depicted. A mass resolving power up to 800000 could be achieved, and it was shown that mass measurements with relative accuracy of a few times 10^{-8} are already feasible at the present stage.

Precision level lifetime measurements [1]

Lifetimes of the first excited states in the even-even ^{112}Ru, ^{112}Pd and ^{114}Pd nuclei, whose precursors were produced in fission of ^{238}U and mass separated, were measured utilizing the Advanced Time Delayed beta-gamma-gamma(t) Method and the detector system prepared at Studsvik. The preliminary results are $T_{1/2}$= 350(25) ps, 62(3) ps and 81(4) ps for the first excited 2^+ states in ^{112}Ru, ^{112}Pd and ^{114}Pd, respectively (see Fig. 4). The new values measured by the slope method are not only more precise than earlier measurements but are also unambiguously assigned to given levels. The new lifetimes for ^{112,114}Pd are considerably shorter (by 35% and 330%, respectively) than the previous imprecise

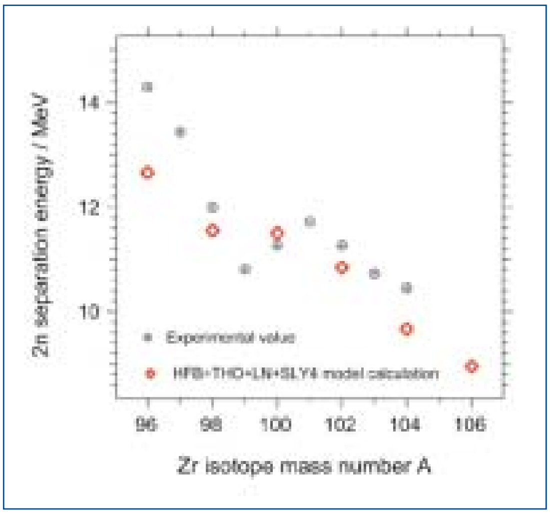

Fig. 2. Two-neutron separation energy for zirconium isotopes between A = 96 and A = 104. Largest experimental errors are smaller than the diameter of marker. Recent theoretical calculation of M.V. Stoitsov et al [Phys. Rev. C 68, 054312 (2003)], shown for comparison, indicates also a change of deformation at A = 98.

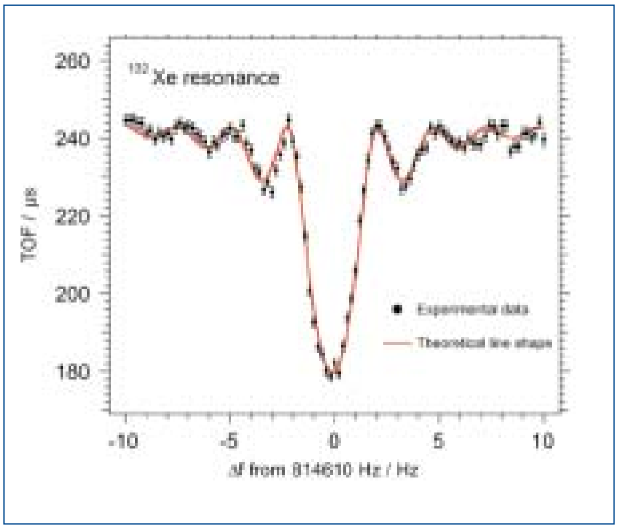

Fig. 3. Time-of-flight resonance for ^{132}Xe, 400 ms excitation time.

results, thus a much stronger quadrupole deformation is determined for these exotic nuclei. The new results will have a strong impact on the model calculations in this region.

Laser spectroscopy [2]

The measurements on the cerium (Z = 58) isotopes were directed at the neutron-rich species near the N = 88 shape change. Isotonic systems above Ce (Nd, Sm, etc) exhibit a substantial shape change between N = 88 and N = 100 but isotones below (Ba, Xe, etc) remain essentially spherical through-out the region. The cerium chain itself had not however been investigated. Fig. 5 shows the differential change of the charge radii of Xe, Ba, Nd, Sm and Ce as function of neutron number from N = 78 - 92. The well known change in gradient on crossing the magic N = 82 shell closure is shown by all the chains and for Nd and Sm the shape change at N = 88 is clearly apparent. The new data for the cerium isotopes show that the N = 88 shape change occurs smoothly with increasing Z and these isotopes display an intermediate behaviour.

Future work on Ce, and other isotope chains including Sc, Y, Zr and Hf, will be aided from the collaboration's development of new laser frequencies and new techniques. Strong ionic transitions in the near-UV, ~ 365nm, will be accessible using newly developed laser frequen-

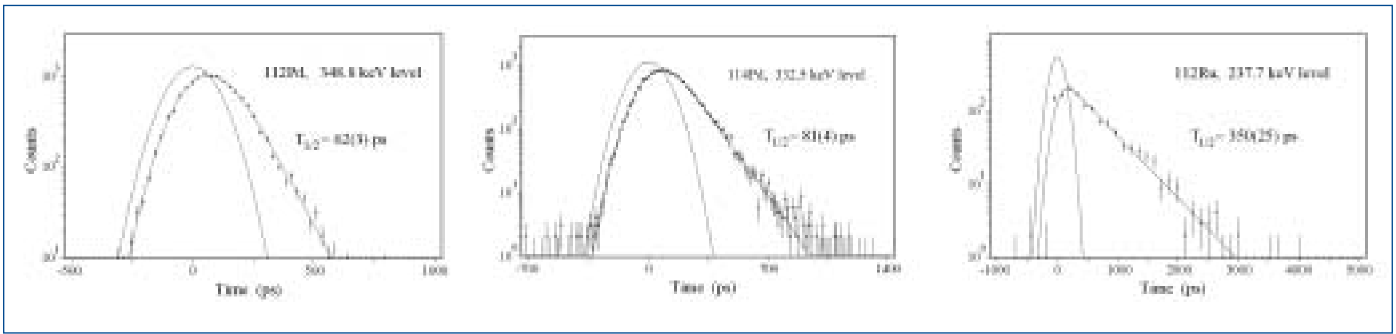

Fig. 4. Lifetime plots for ^{112}Ru, ^{112}Pd and ^{114}Pd first exited states.

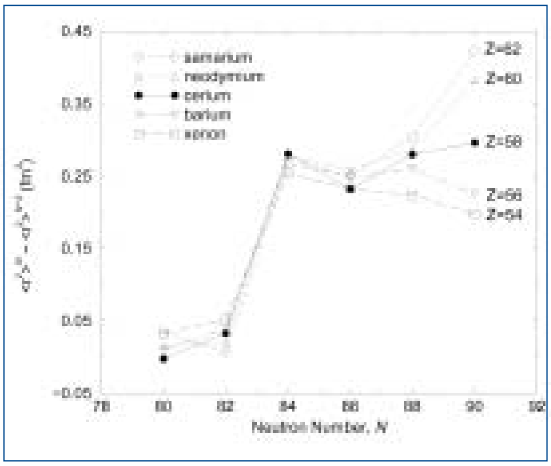

Fig. 5. The differential change of the charge radii as function of neutron number.

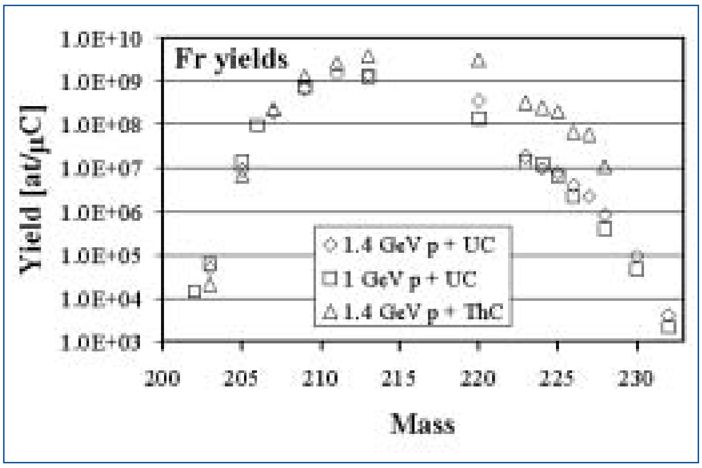

Fig. 6. Yields of Fr isotopes measured at ISOLDE PSB facility at CERN.

Collaborators

Manchester University collaboration
Jon Billowes, head
Paul Campbell, research fellow
Arto Nieminen, postdoctoral researcher
K. T. Flanagan, graduate student
M. Avgoulea, graduate student
B. A. Marsh , graduate student
B. W. Tordoff, graduate student

Birmingham University collaboration
Garry Tungate, head
Dave H. Forest, post doctoral fellow
B. Cheal, graduate student
M. D. Gardner, graduate student
M. L. Bissell, graduate student

[1] Work carried out in collaboration with University of Upsala. Experiment spokesperson: H. Mach, University of Upsala, Sweden.

[2] Work carried out in collaboration with University of Manchester and University of Birmingham. Experiment spokespersons: P. Campbell, Manchester, and J. Billowes, Manchester.

[3] The work at ISOLDE is carried out in collaboration with the Nuclear Matter Program of the Helsinki Institute of Physics.

cies. Such laser light will be used in optical multi-pumping and isomer tagging experiments.

Work at ISOLDE [3]

Fr-isotopes are one of the key isotopes for the next generation radioactive ion beam facilities, since they offer interesting possibilities to study the atomic parity non-conservation which is closely related to lepton-quark interactions through Z_0 gauge boson exchange at small momentum transfer. Since ISOLDE is one of the very few places where thick target yields can be studied with high enough primary beam energies, we examined yields of heavy Fr-isotopes from UC -target and surface ionizer. With such a combination it was possible to reach ^{232}Fr and study its decay to ^{232}Ra. With new data it was possible to confirm the assignment of the $K_p = 0^+$ rotational band in ^{232}Ra.

As a continuation to our studies for ^{72,71,70}Kr, we have developed a new type of thick target. Based on detailed Monte Carlo studies we combined a conventional Nb-foil roll target with the Nb-slab structure in the middle of the target, the latter one being optimized for fast release of short-lived isotopes. We performed a target test where production and release of light Kr-isotopes where characterized. Unfortunately, this new structure was not able to provide high enough yields for ^{69}Kr, which was our goal. Results obtained and their detailed analysis suggest that some other element has to be considered instead of Nb as a target material. We have also continued to research to find an optimum way in producing pure beam of ^{68}Se for high-precision mass measurement of this isotope. This work is still going on and we hope to resolve the problem of contaminating isotopes so that the mass of ^{68}Se can be measured at ISOLTRAP.

Finally, an ion cooler and buncher development has concentrated on the technical design and manufacturing drawings. In the end of 2003, construction of the test bench for the ion cooler with 60 kV high voltage platform and test ion source was also started. This allows immediate access to test beam, which is needed for full characterization of the apparatus before the on-line installation. Although the ion cooler and buncher at ISOLDE aims for improved ion beam transport in general, it is expected that the efficiency of REX-ISOLDE will increase due to better capture of the ion beam. In addition, RFQ opens up a possibility for laser spectroscopy of cooled ion beams, as done already at JYFL.

In-beam spectroscopy

Rauno Julin

In-beam spectroscopy

The majority of the beam time (128 days) at JYFL in 2003 was occupied by the recoil-decay tagging experiments of the first JUROGAM campaign. It was carried out in a collaboration between the JYFL gamma- and RITU groups (Fig. 1) and the groups from foreign institutes listed at the end of the present report. JUROGAM is a Ge-detector array of 43 Phase I Compton-suppressed Ge detectors from EUROBALL and the UK-France detector pool. The JUROGAM array surrounds the target of the RITU separator (Fig. 2) and has the same geometry as the EUROGAM Phase I array had at Daresbury Laboratory in 1992. The photopeak efficiency

Rauno Julin, professor
Sakari Juutinen, senior researcher
Pete Jones, senior researcher
Paul Greenlees, senior researcher
Matti Piiparinen, lecturer
Päivi Nieminen, postdoctoral researcher
Tuomas Grahn, graduate student
Markus Nyman, graduate student
Janne Pakarinen, graduate student
Panu Rahkila, graduate student
Pyry Rahkila, civil cervant 24.2.-

for detection of 1.3 MeV gamma rays is 4.2 %. Combined with the RITU separator and the focal plane GREAT spectrometer, it forms the most efficient spectrometer system for structure studies of heavy proton drip-line nuclei and trans-fermium nuclei in the world. A new differential pumping system (replacing the earlier carbon-window system) was an important development for the in-beam measurements. The much-reduced background enabled in-beam experiments to be run with much higher beam intensities than was previously possible.

TDR

The new Total Data Readout (TDR) acquisition system [I.H. Lazarus et. al. IEEE Trans. on Nucl. Sci. Vol. 48, June 2001] was employed in the collection of prompt events from JUROGAM and delayed events from the GREAT spectrometer, providing a total of over 400 individual spectroscopy channels. The system is a part of the GREAT project, funded by the UK EPSRC and designed mainly by a collaboration of UK institutions. The TDR system collects data in a free running mode, each channel being independent. By the use of time-stamping with a resolution of 10 ns, dead-time problems of the conventional systems used in Recoil-Decay-Tagging (RDT) measurements can be avoided. An advantage of this new approach in data acquisition is that electronic-based coincidence and logic decisions, and extraction of extra relational information between parameters can all be performed in software according to the users' requirements.

Grain

A new event reconstruction and analysis software package Grain [P. Rahkila, to be published] has been developed, primarily for use with the TDR data acquisition system. The TDR system provides a time-ordered stream and event building is done entirely in software. Grain complements the GREAT event builder and can be used in series or in parallel with it, or completely stand-

Fig. 1. The Gamma- and RITU groups

alone. Currently the Grain event reconstruction algorithm emulates a hardware trigger assembling the spatially and temporally correlated data surrounding the "trigger" into events. The package is written in Java2 and thus runs on most platforms without modifications to the source code. The sorting interface is provided as a Java class library, enabling the user to exploit all the features of the primary programming language. The Recoil-Decay-Tagging (RDT) routines are incorporated into the class library and provide access to multi-generation correlation analysis. The first beta version was released in May 2003. Two more beta releases have been distributed since and version 1.0 will be released in the first quarter of 2004. Grain is available for download through the JUROGAM web page at http://www.phys.jyu.fi/research/gamma/index.html.

JUROGAM campaign

The JUROGAM campaign involved 70 foreign collaborators. The spokespersons and collaborating institutes are listed at the end of the present report. After the commissioning test experiments (14 days) in April, several test experiments (7 days) and a total of 13 production experiments (107 days) were carried out:

- In beam gamma-ray spectroscopy of ^{254}No [1]
- Search for spherical, deformed oblate and isomeric states in ^{184}Pb [2]
- Yrast spectroscopy of the neutron deficient nucleus ^{170}Pt [3]
- Rotational band structures in the odd-Z transfermium nucleus ^{251}Md [4]
- Alpha-decay tagging of ^{106}Te and ^{107}Te [5]
- Nuclear structure of the extremely neutron-deficient nuclides ^{161}Re and ^{162}Os [6]

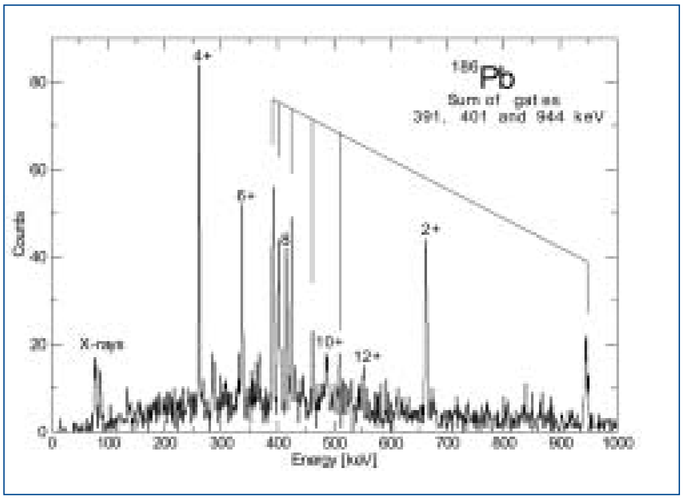

Fig. 3. Sum of in-beam gamma-ray spectra gated with the 391, 401 and 944 keV transitions in ^{186}Pb. The gamma-gamma coincidence data are obtained by tagging with the alpha decay of ^{186}Pb.

Fig. 2. The JUROGAM array coupled to the RITU gas-filled separator

Fig. 4. The plunger device employed with JUROGAM at RITU for RDDS lifetime measurements.

- Gamma-ray spectroscopy of ^{192}Po [7]
- Recoil-Decay-Tagging employing the alpha-decaying nuclei produced in deep inelastic reactions [8]
- The structure of K isomers at the proton drip-line; ^{140}Dy [9]
- A recoil-gated plunger lifetime measurement of ^{188}Pb with JUROGAM and the RITU separator [10]
- Search for an oblate band in ^{186}Pb [11]
- Identification of excited states in the first proton-unbound N=77 isotone ^{146}Tm using recoil-isomer and proton-decay tagging [12]
- Spectroscopy of ^{233}Pa (Z = 91): a step towards octupole deformation studies of high-Z nuclei [13]

Analysis of the new data from these experiments is still in progress. Some preliminary results can already be reported:

The power of the JUROGAM+RITU+GREAT system was demonstrated in the study of ^{186}Pb [11]. The observation of triple-shape coexistence at very low excitation energy in ^{186}Pb has been one of the highlights of nuclear structure physics in recent years [A.N. Andreyev et al. Nature Vol. 405, (2000), 430]. However, due to the low production cross-section and long half-life (4.8 seconds) of ^{186}Pb, it has been difficult to verify this phenomenon in in-beam RDT measurements so far. The high granularity of the GREAT double-sided strip detectors and the high efficiency of JUROGAM enabled the collection of alpha-tagged gamma-gamma coincidences for ^{186}Pb. The ^{83}Kr + ^{106}Pd reaction was employed, to produce ^{186}Pb through the 3n evaporation channel. In addition to the known prolate band, a sum of three gates in the RDT gamma-gamma matrix shown in Fig. 3 reveals a new non-yrast band in ^{186}Pb. However, due to the relatively low transition energies it is difficult to associate this band with the expected low-lying oblate shape.

The Köln group designed a special plunger device for Recoil-Distance-Doppler-Shift (RDDS) lifetime measurements at RITU and JUROGAM (Fig. 4). A retardation foil replaced the stopper foil of a conventional plunger, allowing the use of recoil-gating with RITU. The new system was used to study shape coexistence in ^{188}Pb [10]. The ^{83}Kr + ^{108}Pd reaction was used and recoil-gated spectra were obtained at 10 different target-to-retardation foil distances. In the preliminary spectra, partially- and fully- shifted components of gamma-ray peaks can be seen for transitions up to the 8$^+$ yrast state.

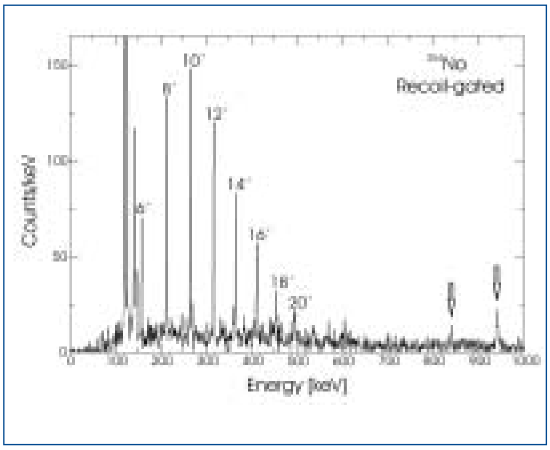

Fig. 5. Recoil-gated prompt singles gamma-ray spectrum from the ^{48}Ca + ^{48}Pb reaction.

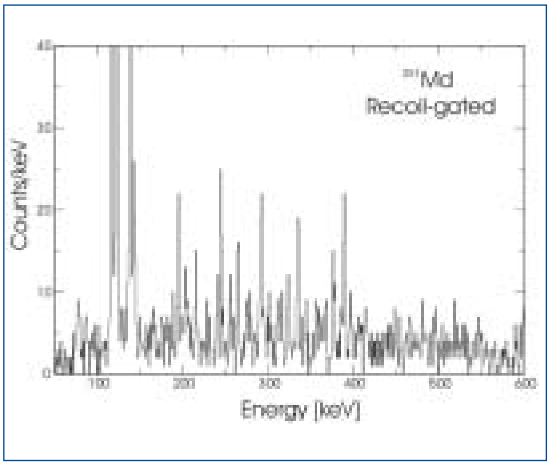

Fig. 6. Recoil-gated prompt singles gamma-ray spectrum from the ^{48}Ca + ^{205}Tl reaction.

Two experiments were performed to continue the series of successful experiments in the transfermium region. The first was a study of ^{254}No [1]. A beam of ^{48}Ca (with intensities of up to 25 pnA) bombarded a ^{208}Pb target of thickness 0.5 mg/cm^2. The preliminary recoil-gated singles gamma-ray spectrum (displayed in Fig. 5) shows the ground state band up to a spin of 22$^+$, and two higher-energy lines from transitions obviously feeding the low-spin yrast states. Analysis of the coincidence data is in progress.

Spokespersons and collaborating foreign institutes

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[8] J. Uusitalo

[9] D. Cullen
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[10] A. Dewald
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[11] J. Pakarinen
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[12] C. Scholey and D. Cullen
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In the second experiment, recoil-gated gamma-ray spectra from the ^{48}Ca + ^{205}Tl reaction were collected in order to investigate proton single-particle states in the Z = 101 nucleus ^{251}Md [4]. The regularly-spaced peaks in the preliminary recoil-gated singles spectrum (shown in Fig. 6) indicate that the yrast cascade in ^{251}Md is formed by stretched E2 transitions.

The RDT studies of the drip-line nuclei in the Os-Pt region were continued by an improved gamma-gamma coincidence experiment for ^{170}Pt, which was produced via the ^{112}Sn(^{60}Ni, 2n) reaction [3]. In the same experiment excited states were observed in ^{169}Pt and ^{173}Pt for the first time.

The ^{58}Ni + ^{106}Cd reaction was used to populate excited states in ^{162}Os and ^{161}Re via the 2n and 2pn evaporation channels, respectively [6]. The ^{162}Os nuclei were produced with a cross-section of only about 150 nb, but still the RDT gamma-gamma coincidence data were sufficient to locate the yrast 8^+ state. In ^{162}Os, the state was observed to lie lower than in any of the lighter N = 86 isotones, revealing the increasing interaction strength between valence protons and neutrons as the proton $h_{11/2}$ shell is filled. The $11/2^-$ isomeric state of ^{161}Re was populated with a cross-section of about 6 mb, while for the $1/2^+$ ground state the cross-section was only about 300 nb. Decay of the $11/2^-$ state via alpha-particle and proton emission was confirmed, but only proton emission from the $1/2^+$ ground state was identified. Preliminary level schemes built on these states have been constructed for the first time using proton and alpha-tagged in-beam gamma-ray spectra.

A first attempt to employ the RDT technique at RITU for nuclei in the neutron-deficient Z = 50 region was made in an experiment to study ^{107}Te [5]. A ^{52}Cr beam impinging on a ^{58}Ni target was used. Careful tuning of RITU reduced the contribution of scattered beam events at the focal plane to a level of 30 %. The maximum recoil rate of about 4000/s at the focal plane limited the beam current to about 4 pnA. An alpha-tagged gamma-ray spectrum for ^{107}Te was obtained. Construction of the level scheme is in progress.

An idea to tag gamma rays emitted by projectile-like binary products with the alpha decay of the target-like partner products from deep inelastic reactions was tested. A target of ^{209}Bi was bombarded by a beam of ^{44}Ca at an energy close to the Coulomb barrier [8]. Preliminary analysis shows that, for example, a gamma-ray spectrum for ^{41}Ar can be obtained by tagging with the alpha decay of ^{212}At.

The second JUROGAM campaign will commence in April 2004.

The JYFL gas-filled recoil separator RITU

Matti Leino

The main activity of the RITU group in 2003 was focused on the recoil decay tagged in-beam γ -ray spectroscopy (JUROGAM campaign) studies. The in-beam part is described elsewhere. The GREAT spectrometer at the focal plane of RITU has replaced the "old" system and has routinely been used for focal plane spectroscopic studies. The planar Ge-detector for low-energy γ rays and X rays was added to the GREAT system. Before the JUROGAM campaign started the GREAT spectrometer was tested using the well known reaction ^{40}Ar + ^{175}Lu -> $^{210,211}Ac$ + 4n, 5n. The idea was to make sure that the GREAT spectrometer combined with RITU functions at least at the same level of sensitivity as the "old" system. At the end of the test run the ^{175}Lu target was replaced with a ^{182}W target with the aim of collecting more α-decay data for the magic nucleus ^{218}U [1].

The GREAT spectrometer was also tested to see whether it could be used for detailed proton decay studies. A reaction of ^{78}Kr + ^{92}Mo was used to produce the proton emitters ^{167}Ir and ^{166}Ir in p2n and p3n fusion evaporation channels [2]. The result was very promising and for example the proton and alpha decays of ^{166}Ir were measured with highly improved statistics.

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Audrey Chatillon, Marie Curie Training Site student -30.4
Karen Van de Vel, Marie Curie Training Site student -30.6.

The RITU separator was successfully used in a large variety of experiments. The heavy element in-beam experiments on ^{254}No [3] and ^{251}Md [4] were performed with very low background conditions. In the lead region many nuclei were studied using both asymmetric and symmetric reactions. The performance of the RITU separator combined with the high sensitivity of the GREAT spectrometer allowed for example much longer searching times to be used when tagging the α decays with γ rays. Close to the limit of RITUs selectivity ^{107}Te [5] was produced using the symmetric reaction of a ^{52}Cr beam impinging on a ^{58}Ni target and was successfully separated from the beam and studied.

Spokespersons and collaboration institutes:

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• A. Chatillon, P. Greenlees, and R. Herzberg
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• B. Cederwall
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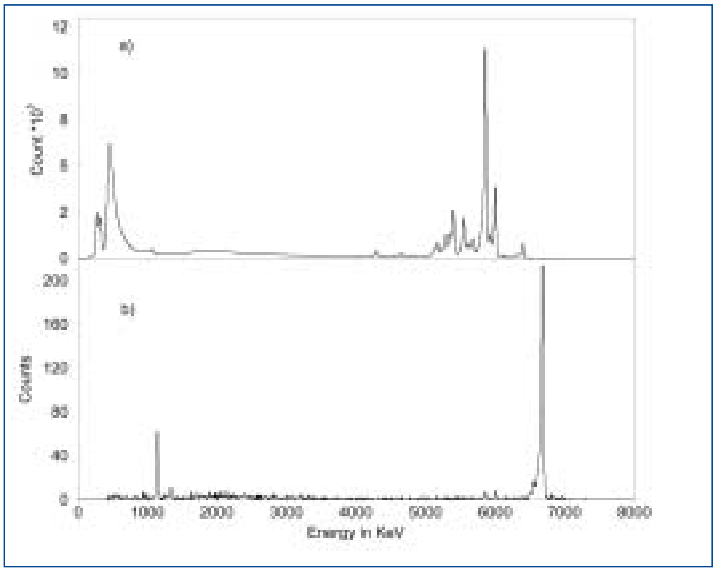

Fig.1. Energy spectra of decay particles measured in the silicon detector and vetoed with the gas counter using the ^{78}Kr + ^{92}Mo reaction: a) all decays; b) decays following recoil implants within 100 ms and tagged by a daughter decay of ^{165}Os with 100 ms searching time. From spectrum b) the mother decays of ^{169}Pt (α-decay line) and of ^{166}Ir (proton-decay lines) can be recognized.

Nuclear reactions

Wladyslaw Trzaska

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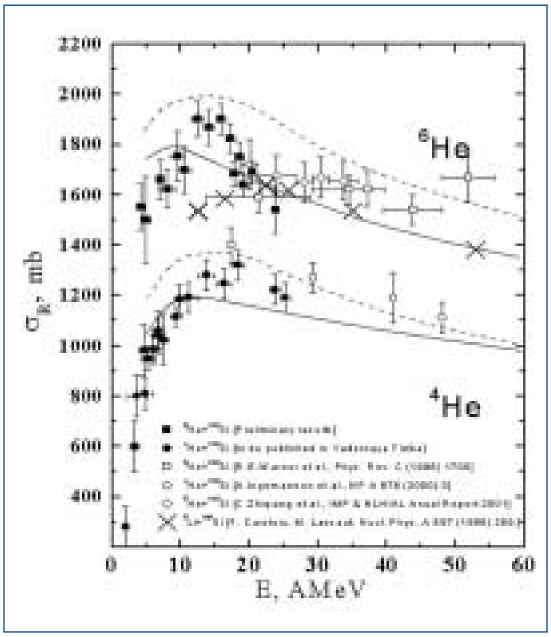
Valery Rubchenya, senior researcher
Vladimir Lyapin, researcher (HIP/JYFL)
Serguei Iamaletdinov, graduate student
Tomasz Malkiewicz, graduate student
Jaroslaw Perkowski, Marie Curie Training Site student -11.8.
Heidi Parviainen, MSc student

With the help of our outside collaborators who have spend 980 visitor-days in Jyväskylä, the nuclear reaction group has performed 12 in-beam experiments that used up 1300 hours of the cyclotron's beam. We have also significantly contributed to 4 experiments at the other European laboratories. This statistics reflects the intensity of our experimental work in 2003. All in all a lot of data have been collected and it will take some time before all of it are analysed.

Perhaps the most spectacular result of 2003 is the first strong evidence for Collinear Cluster Tripartition (CCT) – the new exotic decay mode in which a heavy nucleus, in our case ^{252}Cf, instead of fissioning disintegrates into 3 fragments of comparable mass determined by the magic clusters available to the system. The key decay characteristic of CCT is that the central fragment remains nearly at rest while the outer 2 fragments fly out in a fashion very similar to the normal binary fission. CCT has not yet



been independently confirmed but with two dedicated experiments planned for the nearest future one might expect some new exciting developments soon.

Naturally, our interest in fission is not limited to fine structure effects. On the contrary, fission dynamics, neutron, gamma-ray and light charged particle emission at various stages of fission continue to dominate our research program. We have also made investigations of angular distribution of fission fragments to disentangle the compound nucleus (CN) fission from the quasi-fission component in several nickel and calcium induced reactions leading to superheavy nuclei.

Fission fragments can be studied not only with active detectors like the gas-filled position sensitive avalanche counters used at HENDES or CORSET-style microchannel plate detectors but also with tracking foils. In fact this is the best way to reach cross-sections down to the level of pico barns. This way we have measured the excitation function of the ^{22}Ne + ^{208}Pb fusion-fission reaction reaching the cross section 4 to 5 orders lower than those reachable in traditional experiments. This measurement made an important contribution to the study of cluster radioactivity as it validated the "alpha-cluster-like" mechanism of cluster radioactivity for the emission of fragments with the masses up to A = 22.

We have also studied cluster effects in lighter system by investigating the reaction ^{28}Si(^{6}Li,d) in direct and inverse kinematics – ^{6}Li(^{28}Si,d). We have made precise measurements of the total cross section of ^{4}He + ^{28}Si reaction, and extended the data on ^{16}O + ^{14}C at large angles for our rainbow scattering studies.

Last but certainly not least we have made considerable progress in energy loss measurement of heavy ions by reaching the absolute accuracy of 2% and extending the energy range covered in a single measurement to the record span of 1:445 (0.03 – 11 MeV/u).

Ion beam based materials physics and applications

Ari Virtanen and Vladimir Touboltsev

Ion beam based methods for scaling down and modification of nanostructures

Applicability of any processing method to nanofabrication is determined by two not fully independent criteria. First, the method should provide a reproducible and controllable way to form a nanostructure of desired properties and functionality at our will. The second criterion is related to controllable and reproducible modifications of internal properties without causing any appreciable changes to the external morphology and microstructure. Since characteristic dimensions of the functional elements in IC technology constantly decrease on a nanosize scale following the general trend of minimization, the criteria imply more and more strict compatibility constraints ruling out techniques uncompetitive in the downsizing racing.

In the project related to application of ion beams for fabrication and modification of nanosized structures both aspects are addressed. On the one hand, applicability of energetic ions for scaling down of prefabricated structures is studied aiming at achieving dimensions unattainable by conventional methods (e.g. by electron beam lithography). On the other hand, modification of nanostructures internal properties is achieved via employing ion implantation as a far-from-equilibrium technique for fine-tuning of the structures functionality and performance at our will. Reproducibility and controllability of the ion beam methods are given a special attention in evaluating to what extend ion beams are in general applicable to nanoelectronic components and circuits.

The project is carried out in collaboration with group of Nanotechnology and Physics of Nanostructures at JYFL.

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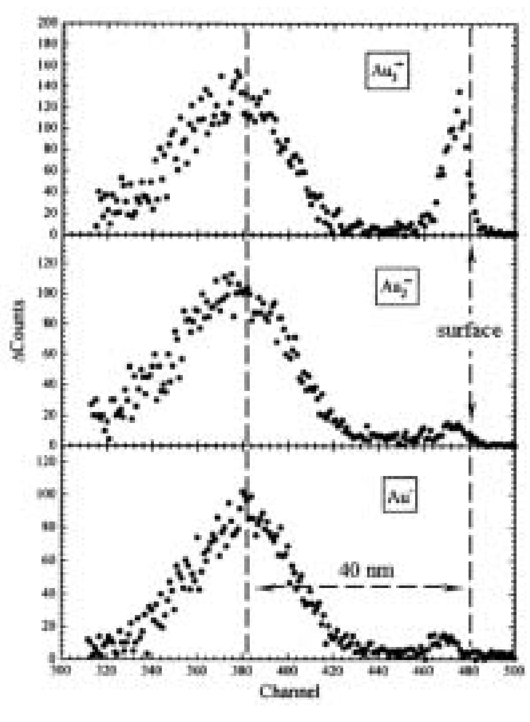

Fig. 1. Range distributions for 100keV/atom Au_n (n=1-3) implanted into preamorphoused Si.

Ion implanted cluster ranges in matter

Cluster bombardment of metals and semiconductors was shown to produce strong non-linear effects first observed in sputtering. For interpretation it is important to know, whether implantation as clusters modifies the nuclear stopping in matter but particular for heavy implants this question remained unstudied up to the present day.

http://www.phys.jyu.fi/research/ion-matter/index.html
http://www.phys.jyu.fi/research/applications/index.html


Fig. 2a.

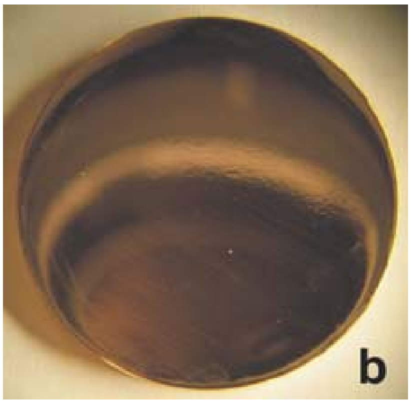
Fig. 2b.


Fig. 3.

Fig. 2. Cu disc with imprinted word "JYFL" before (a) and after (b) polishing.

Fig. 3. The word "JYFL" previously imprinted and mechanically erased from the disc has been revealed by ion irradiation.

In the present work ranges and range straggling of Au_n (n=1-7) clusters implanted into various polycrystalline and amorphous matrices (e.g. Al, Si, Cu) with energies of 10-100keV/atom were studied. The measurements had a twofold purpose, viz. first to form a basis for interpretation of the very large non-linear effects recently observed when clusters interact with matter and resolve the question of the nuclear stopping of clusters. The second purpose was to find out whether it was experimentally possible to verify theoretical models describing cluster-matter interaction. The experiments revealed strong dependence of the cluster interaction with matter on aggregation state, i.e. number of atoms in clusters. For example, significant difference between the depth distributions of Au and Au_3 implanted into Si matrix is obvious in Fig.1.

The project has been carried out in collaboration with Ørsted Laboratory, the Niels Bohr Institute, Denmark.

Ion irradiation for imaging of deformed surfaces

Search for new methods for visualization of deformations in solids is of importance for various often interdisciplinary fields of science and technology, e.g. materials physics and processing, construction design, medical applications, forensic studies, art attribution, etc. Always when deformations and stress are involved and critical for functionality of a material, precise knowledge about distribution of the resident deformations is required in order to avoid undesirable trend in the material properties. On the other hand, stress induced deformations can be sometimes a "storage" of latent information that is difficult or even impossible to reveal by other methods, e.g. in forensic studies (visualization of imprinted identification numbers and characters erased accidentally or on purpose from the surface of guns, etc.). A key question in this case is how to reveal hidden information without severe degradation of the substrate material?

Ion irradiation was found to be a powerful tool for investigation of deformations in metals. Fig.2a shows a copper disc sample with word "JYFL" imprinted by conical indenters. Imprinting introduced into surface plastic deformations associated with the characters contours. Subsequently, the surface of the sample was mechanically polished so that no traces of the imprinted word could be seen (Fig.2b). After polishing, the irradiation method was applied to the sample and is seen in Fig.3 to reveal the erased image.

The method obviously is very promising for various applications. Straightforward application is visualization and revealing stamped numbers and characters erased from metallic surfaces, e.g. in forensic examinations in police matters. Forensic experts from the Crime Lab of National Bureau of Investigation expressed their interest in the method.

Diffusion studies by radiotracers

Silicon-germanium alloy (SiGe) has been under intensive study during the last years, since it has turned out to be a promising candidate for the electronic industry as a

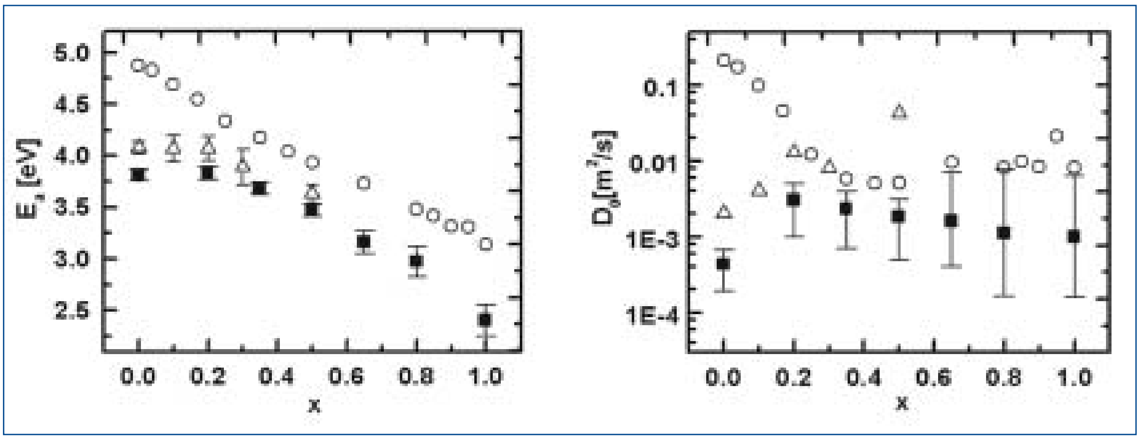

Fig. 4. Activation enthalpies E_a (a) and pre-exponential factors D_0 (b) as a function of $Si_{1-x}Ge_x$ composition (x) for As (¢), Sb (r) (from A. Nylandsted Larsen et al., Appl. Phys. Lett. 68 (1996) 2684) and self-diffusion (Å) (from A. Strohm et al., Z. Metallkd. 93 (2002) 737).

substituting and accompanying material for Si in integrated circuits.

Arsenic diffusion properties have been determined in intrinsic relaxed $Si_{1-x}Ge_x$ epi-layers by radiotracer method for the full range of x=0-1. Comparison with other impurity atom- and self-diffusion in Si, Ge and SiGe showed that both interstitials and vacancies contribute as diffusion vehicles in the composition range $0 \le x \le 0.35$ and that vacancy mechanism dominates in the range $0.35 < x \le 1$ (Fig. 4).

RADEF facility

Many test campaigns were performed at RADEF during the year 2003. People from several countries representing institutes and companies like ESA, Astrium Space, Hirex Engineering, Saab-Ericsson Space, CERN and Helsinki Institute of Physics were involved in the tests.

Today many advanced semiconductor IC's are assembled the way (TSOP package), that they cannot be SEE tested from the front side due to shadowing lead frame and accelerator ion penetration limitations. Backside irradiation on thinned IC's with high penetration ions is the only solution. Here the JYFL facility has the main advantage since the 14 GHz ECR ion-source provides very high charge state ions resulting in a much deeper ion penetration range; a factor of 2 to 3 improvement, compared to the values attained by using the old 6.4 GHz ECR ion source.

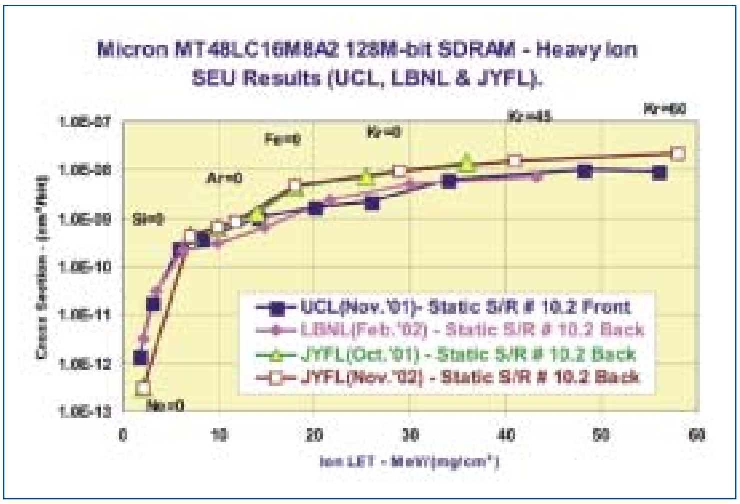

Fig. 5. Comparison of the SEU data taken in the three laboratories: UCL, LBNL and JYFL (private comm. with Mr. Reno Harboe-Sørensen, ESA/ESTEC).

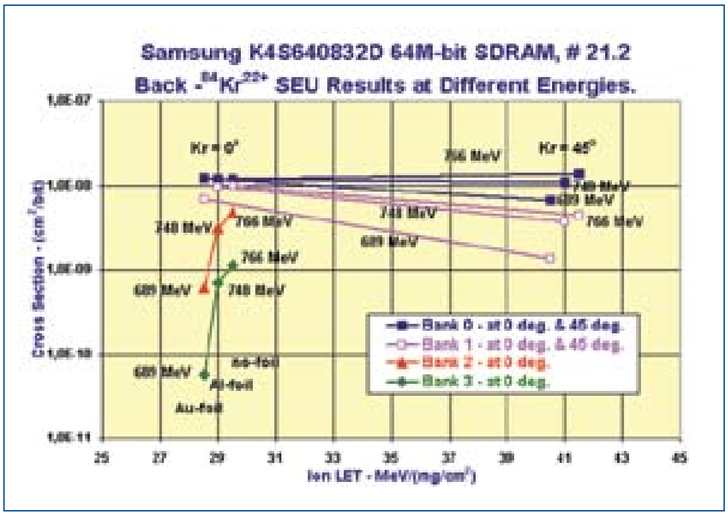

Fig. 6. Effect of ion penetration to the SEU data. The energies of krypton ions were adjusted with the degrader foils. One can see the effect in banks 2 and 3 already in normal incidence (i.e. at 0°), but for banks 0 and 1 the phenomenon becomes more emphasized when tilting to 45°.

Fig. 7. Dr. Eija Tuominen, the leader of the HIP/CERN research group, monitoring accumulated radioactivity after proton irradiation.

In order to validate the usability of high penetration ions for back side irradiation, earlier and recent test data taken on a thinned Micron 128Mbit SDRAM were compared with data obtained from both the HIF, Belgium and from the LBNL, Berkeley, USA. In Fig.5 SEU results, presented as cross section (cm^2/bit) versus ion LET (MeV/(mg/cm2), are presented. The HIF data are front irradiated results obtained on an identical device whereas the LBNL data are from the same device as used at JYFL (back irradiated).

Considering variability in test set-up, tester, ion counting and calibration, data analysis and interpretation, fairly good correlation can be reported between the four sets of data.

The importance of the ion penetration is illustrated in Fig.6. Caused by the uneven thinning the small deviations in the distances to the different banks become visible with only small differences in ion ranges, i.e. 89, 97 and 99 microns. These correspond to the ion energies of 689, 748 and 766 MeV, respectively (note the artificial difference in LET- values for visualisation).

For probing the upper limits we started a new development work with the aim to push the penetration range steadily over 100 micrometers and, with some specific ions and beam cocktails, obtain still a factor of 1.3 to 1.5 higher penetrations with the desired LET range. The plan includes an installation of the new TWTA amplifier in our ECRIS II. Some preliminary results are presented elsewhere in this report.

Cooperation with Helsinki Institute of Physics and their CERN collaboration also continued. The group performed two long irradiation campaigns by studying the radiation durability of Czochralski-, float zone- and oxygenated float zone silicon detectors in the proton beams at different energies. The results are reported elsewhere in many publications and conference contributions.

Major collaborators for ion beam based materials physics research:

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- W. Frank, A.Strohm, T. Voss, Universiät Stuttgart and Max-Planck-Insitut für Metallforschung, Stuttgart, Germany
- CERN/ISOLDE collaboration, Geneva, Switzerland
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Major foreign collaborators for accelerator based applications:

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- L.Granholm, Swedish Space Corporation, Sweden

Nuclear Structure, nuclear decays, rare and exotic processes

Jouni Suhonen

Jouni Suhonen, professor
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Jussi Toivanen, postdoctoral researcher
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Markus Kortelainen, graduate student
Jenni Kotila, graduate student
Sami Peltonen, graduate student

Nuclear structure of solar-neutrino detectors

We have performed nuclear-structure calculations for groups of isobaric nuclei in the regions of the solar-neutrino detector nuclei ^{71}Ga and ^{127}I. These microscopic calculations have been done using the MQPM, the microscopic quasiparticle-phonon model for nuclei with odd proton or neutron numbers. By using realistic effective interactions, very good results for the energy spectra have been obtained. Some short-comings in description of charge-changing transitions, like beta decays and Gamow-Teller strength functions, have been observed when using the MQPM framework. These calculations have been performed in order to see the predictive power of the used nuclear-theory formalism in quantitative description of solar-neutrino detection in current and future large-scale experiments in various underground laboratories.

Muon capture and the double beta decay

A reliable theoretical description of double-beta-decay processes needs a possibility to test the involved virtual transitions against experimental data. Unfortunately, only the lowest virtual transition can be probed by the traditional electron-capture or beta-decay experiments. We have proposed that calculated amplitudes for many virtual transitions can be probed by experiments measuring muon-capture rates to the relevant intermediate states. The capture process is called the OMC (ordinary muon capture) and involves the capture of a negative muon from the atomic s orbital without emission of a gamma quantum. We have calculated double beta decays and the corresponding OMC transitions for several nuclei in the frameworks of the proton-neutron QRPA and the nuclear shell model using realistic effective interactions. First measurements of this process for double-beta-decaying nuclei have been performed in the Paul Scherrer Institute (PSI), Villigen, Switzerland in 2002. The analysis of this data is in progress and a proposal for a complementary measurement at PSI has been launched.

Supersymmetric dark matter: calculation of LSP detection rates

Recent particle-physics theories seem to favour light supersymmetric particles (LSP), like the neutralino, as possible constituents of cold dark matter (CDM) of the Universe. To shed light to this problem one needs reliable estimates of the LSP-nucleus scattering cross sections for possible detection of this component of the dark matter. We have performed the LSP-nucleus cross section calculations for ^{71}Ga, ^{73}Ge and ^{127}I detectors, expected to be efficient detectors of the LSPs. The calculations are done by using the microscopic quasiparticle-phonon model (MQPM), originally developed by our group to study the structure of odd-mass nuclei from a microscopic point of view. The calculated detection rates per year and kilogram of detector material have been shown in Figure 1 for the ^{71}Ga (the blue/violet area) and ^{127}I (the red/violet area) nuclei. The shaded areas represent the ranges of detection rates for different supersymmetric models and parametrizations of the corresponding Lagrangians. The results for the ^{73}Ge nucleus correspond very closely to the ones of ^{71}Ga. Futher calculations are being done in the nuclear shell model for the ^{71}Ga, ^{73}Ge nuclei, and also the inelastic channels will be studied.

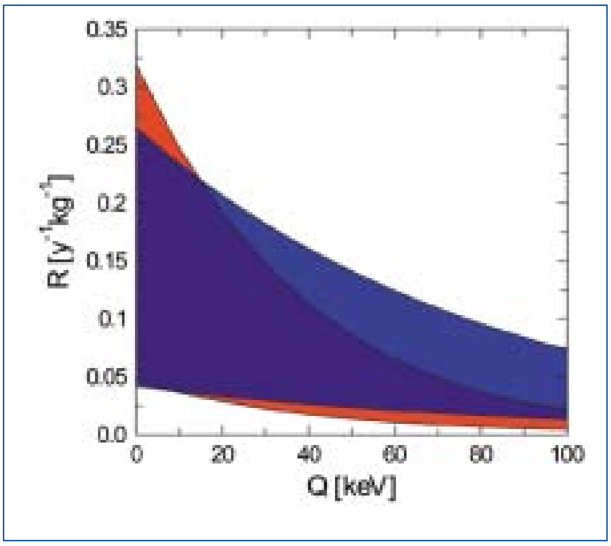


Figure caption: Calculated LSP detection rates per year and kilogram of detector material for the ^{71}Ga (blue/violet area) and ^{127}I (red/violet area) nuclei within several supersymmetric parametrizations.

Systematic study of alpha decays to excited 2^+ and 0^+ states

We have performed a systematic, fully microscopic calculation of hindrance factors of alpha decays to excited 2^+ states in spherical and nearly spherical nuclei. The basic nuclear-structure framework consists of the use of the BCS method to create two-quasiparticle excitations and to use the quasiparticle random-phase approximation (QRPA) to take into account collective degrees of freedom in the alpha-decay daughter nucleus. Several isotopic decay chains are being treated within this framework in order to study the interplay between the isoscalar/isovector part of the interaction and the alpha-decay rates. Also similarities in the behaviour of the electromagnetic decay rates and alpha decay rates are of interest. Further studies are planned for scanning the decays to the first excited 0^+ states. These are processes of great experimental interest at the present.

Microscopic description of two-phonon states

Microscopic description of low-lying two-phonon states in even-even nuclei has been developed. The main building blocks are the quasiparticle random-phase approximation (QRPA) phonons. A realistic microscopic nuclear hamiltonian is diagonalized in a basis containing one-phonon and two-phonon components, coupled to a given angular momentum and parity. The QRPA equations are directly used in deriving the equations of motion for the two-phonon states. The Pauli principle is taken into account by diagonalizing the metric matrix and discarding the zero-norm states. The electromagnetic and beta-decay transition matrix elements are derived in terms of the metric matrix. The model has been applied to describe electric quadrupole transitions in the ^{106}Pd and ^{108}Pd nuclei, in the $^{110-130}Cd$ chain of isotopes, partly relating to the experimental work of the IGISOL group, and in the $^{98-106}Ru$ chain of isotopes. Encouraging results have been obtained. Further studies are being done for the beta-decay properties of these nuclei.

Light-neutrino mass spectrum and observability of neutrinoless bb decay

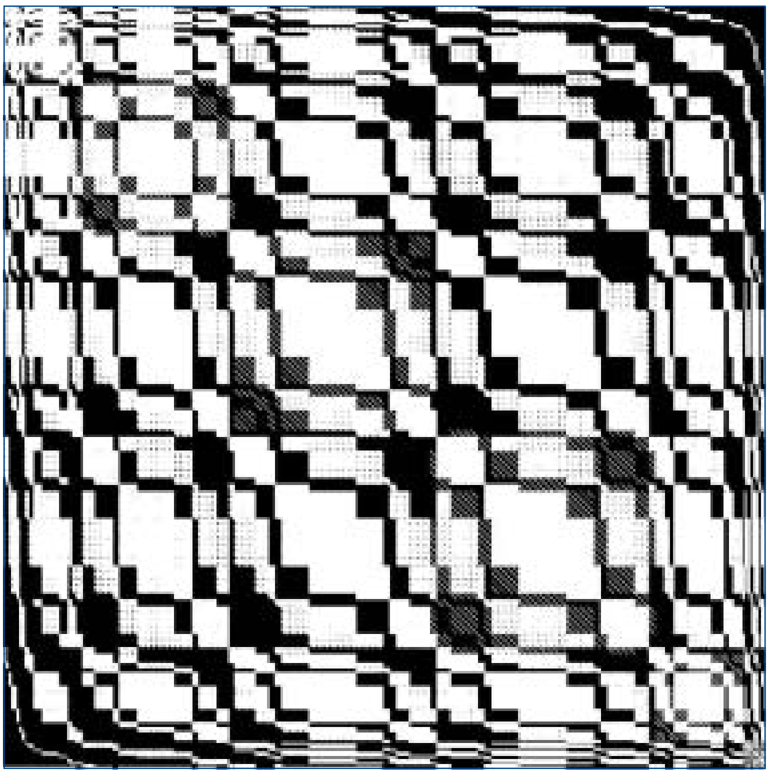
We have studied the implications of the light-neutrino mass spectrum on the observability of the neutrinoless double beta decay. As special cases of the used formalism one can treat the implications of the normal and inverted hierarchical neutrino-mass spectra. The role played by the involved nuclear matrix elements has been addressed for the ^{76}Ge decay in detail. We have also studied the neutrinoless double beta decay to excited 0^+ states with the aim of finding promising candidates to probe sub-eV neutrino masses in modern underground experiments using huge active-mass detectors. Almost all possible candidates have been treated by using a microscopic calculational framework called the MCM (multiple-commutator model), developed originally by our group to study beta decays of double-odd nuclei to excited states of the final double-even nuclei.

New shell-model code for nuclear-structure calculations

The shell-model code EICODE has been designed to carry out very big nuclear shell-model calculations. The code calculates Hamiltonian matrix elements 'on the fly' and thus avoids the matrix storage problems that conventional shell model codes, such as OXBASH, suffer. The mathematical method to achieve that is the so called proton-neutron partitioning method, used in the well known shell model codes ANTOINE and NATHAN by F. Novacki and E. Caurier. Furthermore, EICODE uses many-body basis states projected to good angular momentum. That makes it possible to reduce the dimensions of Hamiltonian matrices by up to two orders of magnitude compared to m-scheme shell-model codes. So far our biggest calculations for nuclei ^{73}Ge and ^{71}Ga using EICODE have matrix dimensions of the order of 1.4 million and have contained about 15 million Slater determinants per wavefunction. This kind of dimensions are a practical upper limit for todays serial workstations. However, the structure of our code is such as to allow very effective parallelization. A parallel version of EICODE running in a massively parallel supercomputer will be able to find the lowest eigenstates of shell-model Hamiltonian matrices of the dimension of 25-100 million and produce wavefunctions containing up to a couple of billion Slater determinants. The parallel version of EICODE is currently under construction.

Large-scale nuclear-structure simulations

The goal of the project is to create a transparent, user-friendly environment for nuclear-structure simulations, which will combine solid, numerically feasible, microscopic many-body theories with extensive libraries of experimental data utilising state of the art computational and IT tools. The MOVA (Monster-Vampir) model family used is based on solid approximations of the exact many-body problem, progressively applicable on the entire chart of nuclei. The burning issue here, and in general in nuclear-structure theory, is that no parameter-free, practically applicable many-body theory exists. Thus, free parameters to be fixed by experimental data remain. We use (on line) extensive sets of experimental data provided by the data banks in connection with the simulations in order to fix the free parameters in an optimal, automatic way applying suitable minimization methods. Currently, the real mean-field MOVA-models have been modified to allow userfriendly calculations globally on the entire chart of nuclei. Energies of the first excited 2^+ states of all known doubly even nuclei are used as the first experimental data set to be studied. Preliminary results using a G-matrix as a two-body interaction are promising.



A 10432-by-10432 Hamiltonian matrix of the EICODE for the nucleus ^{28}Si. Every pixel is a 10-by-10 matrix, and the intensity of the grey in a pixel is proportional to the number of non-zero matrix elements.

Materials physics

Physics of nanostructures and nanotechnology

Ilari Maasilta

http://www.phys.jyu.fi/research/nanotech/index.html

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Terhi Hongisto, MSc student
Kari Riikonen, MSc student

Nanophysics research at Jyväskylä has continued its main directions of studies of thermal and superconducting nanodevices at sub-Kelvin temperature range, in addition to development of nanofabrication processes.

Thermal properties of nanostructures and microcalorimeter development

The main research direction of the thermal nanostructure research team led by Dr. Maasilta is to (a) understand energy flow mechanisms from electronic to phononic degrees of freedom and within the phonon system in restricted, low-dimensional geometries, and (b) ulitize this knowledge in the development of ultradsensitive thermal and radiation sensors (bolometry).

Electron-phonon interaction in nanostructures

We have continued to utilize normal-metal-superconductor tunnel junctions (NIS) for ultrasensitive thermometry. These can be used to characterize the electron-phonon interaction in metals very accurately. Fabricating samples of varying mean free path, we have investigated the role of disorder in the electron-phonon interaction with a striking novel result: as the sample crosses over from a disordered regime to the ordered limit, the interaction changes its strength. The result has been theoretically predicted recently, and our measurements seem to be the first confirmation of this effect. The change of the strength of the interaction with disorder can possibly be used in designing more sensitive detectors. Since the dimensionality of the

Fig. 1. From the left: Ilari Maasilta, 2003 Nobel Laureate Anthony Leggett, Konstantin Arutyunov and Gheorghe-Sorin Paraoanu.

lattice should also have a strong effect on this interaction, work is in progress to measure the interaction in suspended membrane and wire geometries.

Superconducting Transition Edge Sensors (TES)

Superconducting transition edge microcalorimeter develop-ment continued with two different ESA funded projects. The first project, in collaboration with Metorex International Oy, aims to optimise the performance of a single pixel in terms of energy resolution and speed. The long term goal for ESA is to develop a cryogenic imaging spectrometer in the 0.1– 10 keV band with a few eV resolution, to be installed onboard a satellite (XEUS).

To achieve the targets for the performance, the noise properties of these devices need to be understood better. Especially, the origin of so-called excess noise needs to be thoroughly characterized. We have developed a model for this noise, based on the fluctuations of the superconducting phase transition, which accurately models the observed noise in measured devices (fig. 3). To gain a fuller understanding, we have built a state-of-the-art measurement setup utilizing a ultrasensitive superconducting quantum interference device (SQUID) current preamplifier installed in our homemade dilution refrigerator (fig 4.). The SQUID-setup development has been performed in collaboration with the National Institute of Standards and Technology (NIST) in Boulder, Colorado.

The excess noise studies require development of different optimal detector geometries. Fig. 5 show examples of novel TES geometries we have fabricated to understand the excess noise behavior.

We are also involved in another ESA funded project in collaboration with the Space Research Organization Netherlands (SRON), which aims at developing an array of TES sensors for the x-ray imaging spectrometer of ESA's XEUS mission. When designing an array, it is important to know the thermal properties of the used materials at low temperatures (< 100 mK). Parameters such as Kapitza resistance and electron-phonon coupling of the detector metals and thermal conductance of the

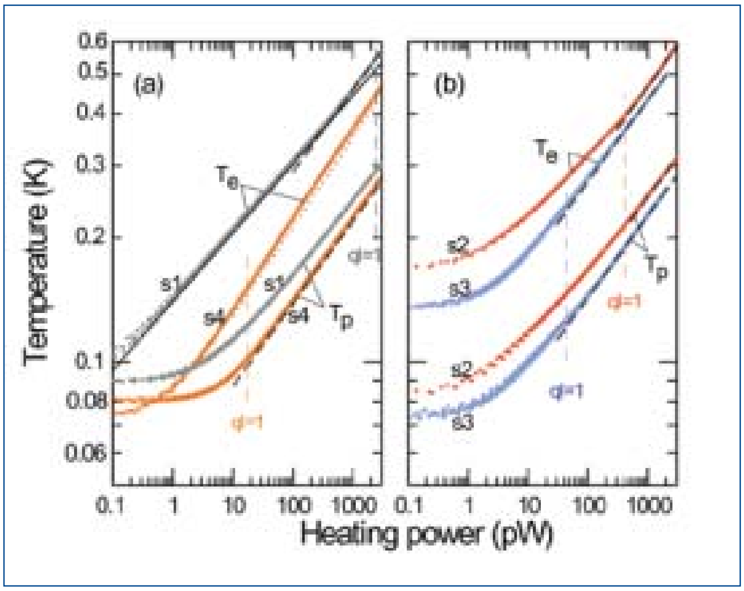

Fig 2. Measured electron and phonon temperatures vs. dissipated Joule heat power. Theoretically, the crossover between the ordered and disordered regimes happens at ql=1, where q is the phonon wave vector and l the electron mean free path. Transition is most clearly seen for the electron temperatures of samples s1 (at P= 600 pW) and s2 (P=200 pW).

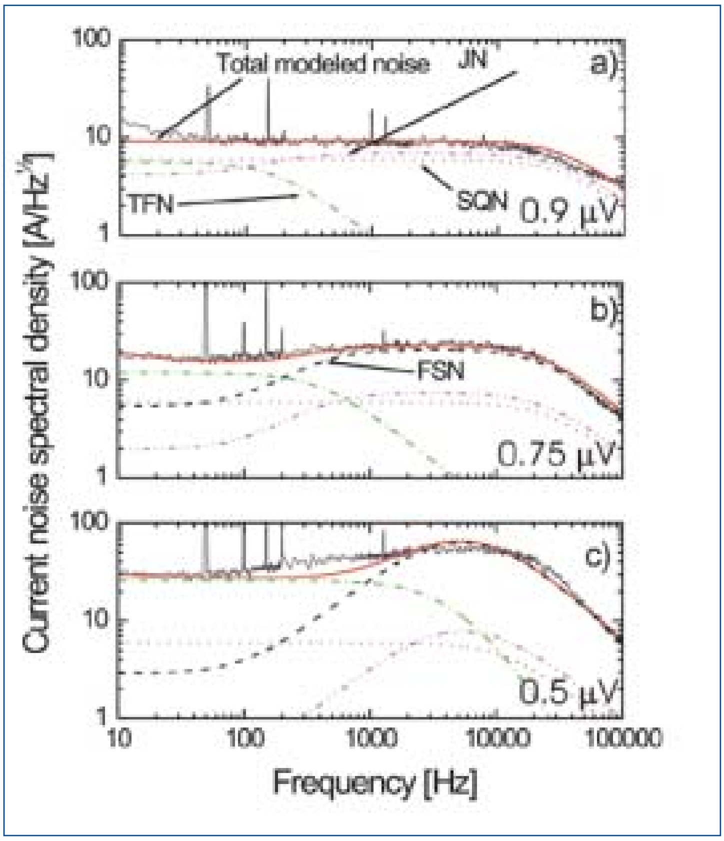

Fig 3. Measured current noise spectra of a TES device at three different voltage bias points. The red curve is the model containing the novel fluctuation superconductivity noise (FSN).

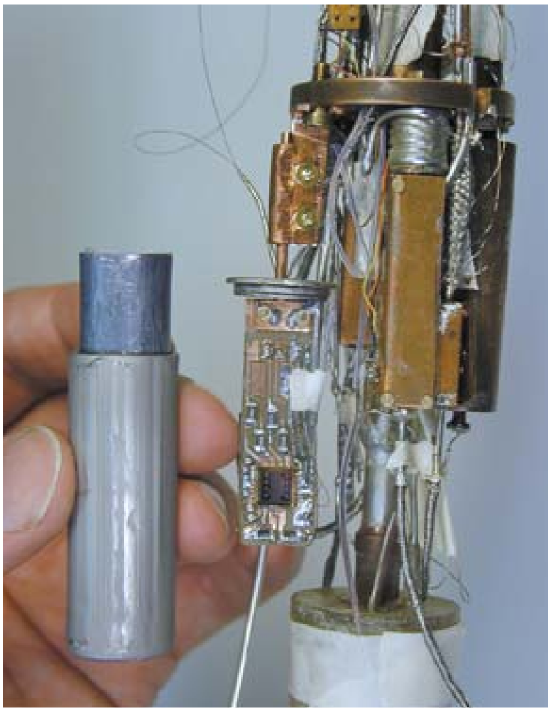

Fig 4 Ultrasensitive two-stage SQUID current amplifier circuit installed in the 1.5 K flange of a dilution refrigerator. Gray metal tube is a magnetic shield.

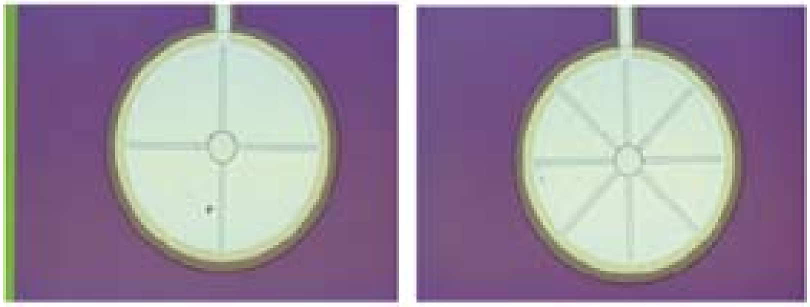

Fig 5. Micrographs of two different TES sensors in "pizza" geometries. (Sliced TES).

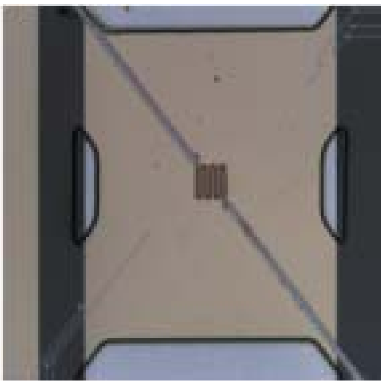

Fig. 6 A SiN membrane sample for the measurements of thermal conductance at sub-Kelvin temperatures.

support structure are under study. Fig. 6. shows a sample that was used to measure the thermal conductance of a SiN membrane for single pixel. A heater is placed in the middle, and temperature at various points in the membrane is measured by SINIS thermometers.

Quantum Engineering (QE)

The Quantum Engineering (QE) team of the NanoPhysics group directed by Dr. S. Paraoanu has focused on issues related to quantum devices based on the Josephson effect in small superconducting junctions.

Cooper pair pumps

We took part in the experiments done in the PICO group (J. Pekola) at HUT on transport in a three junction Cooper pair pump operated as a turnstile. The samples fabricated in Jyväskylä were measured in a 7 mK base-temperature refrigerator at the Low Temperature Lab (HUT) in Helsinki. The turnstile operation in this system is possible due to the hysteretic behaviour within the triangle opened around each triple node in the honeycomb stability diagram. A simple way to describe this process is to consider a path in the (q_1,q_2) plane with the constraint $q_1 = q_2 + const.$, exiting the triangle at both extremes, and to assume that at every degeneracy point of the charging Hamiltonian, H_{ch}, the system is driven into the state with lower energy. The argument is sufficient to explain the turnstile behaviour: within every traversal of the path one Cooper pair is transferred through the array in the direction of the bias voltage. This principle of operation involves coherent tunnelling, cotunnelling and relaxation of Cooper pairs.

In Figure 7 below we present the results from one of the experiments, where the measured current $I = \Delta I + I_0$, is shown as a function of the operating frequency f. The 'pumped´ charge per cycle $2eQ_P$, is found by fitting the current with the expression

$$I = 2efQ_P[1\text{-exp}(-f_{LZ}/f)] + 2efQ_L + I_0,$$

where the reduction of the current due to Landau-Zener interband transitions at frequencies above f_{LZ} and the leak current, Q_L, due to inelastic tunnellings, have been taken into account. Values obtained from the fit are $Q_P =$

(0.985 ± 0.068), f_{LZ} = (26.2 ± 4.4) MHz and Q_L = (0.127 ± 0.046).

Transport phenomena in SET's

In continuation of our work on Nb SET's the QE team has investigated in more detail the potential of these structures for reducing the dephasing effects associated with the presence of nonequilibrium quasiparticles on the island. In the case of AlNbAl SET structures, it is expected that these processes will be suppressed due to the relatively large energy required to break the gap of Nb. However, in the samples that we have fabricated and measured, it turned out that several tunnelling effects coexist below the quasiparticle threshold voltage, where a rich structure of peaks and steps appears in the IV (see Figure 8). To identify what processes are responsible for these features we have fabricated several AlNb and AlAl single junctions and measured them at various magnetic fields and temperatures. This allowed us to characterize or eliminate effects such as resonances due to the electromagnetic environment, MAR, MPT, 3e-tunneling, etc. We found that resonant tunnelling of Coper pairs is responsible for the series of equally-spaced peaks in the IV, and a process analog to the elastic co-tunnelling in normal-metal SET's can explain the changes seen in the background current when a external magnetic field is applied. The theoretical description of this process is that of a second-order tunnelling process through a virtual state corresponding to an excitation in the Nb island.

Suspended structures

The QE team has fabricated and measured a new type of SET structure. It is known that a major limitation for many superconducting devices is the 1/f noise that originates from the substrate. Apparently, the only way to avoid this is to use substrates with lower noise. But a more radical idea is to remove the substrate altogether! We have succeeded in fabricating a "suspended" Al single-electron transistor (SUSET) in which the island "floats" above the substrate (see Figure 9). The structure was remarkably resilient even after repeated cool-downs and mechanical manipulations, displaying the well-known SET features in the IV and conductance.

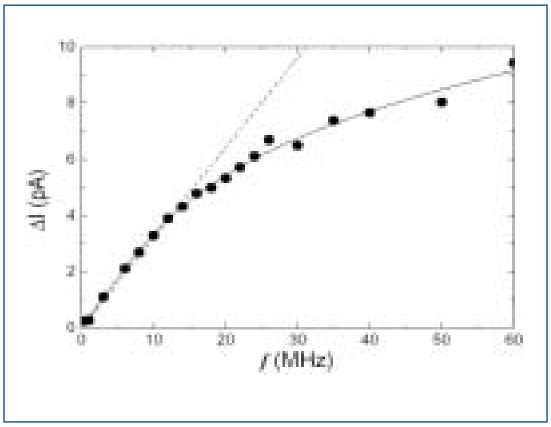

Fig. 7. Current in a cycle through the degeneracy node of the stability diagram of the three junction CPP as a function of the frequency of the RF-signals applied in-phase to the two gates. The bias voltage was $V = 50$ mV and the AC-amplitude 1/6 times 2*e*-period in $V_g C_g$. The solid line is the fit by the equation above and the dashed line shows the ideal 2*ef*-dependence predicted by the theory. Other sample parameters were E_C ª 129 meV and E_J ª 19 meV, yielding E_C/E_J ª 0.15.

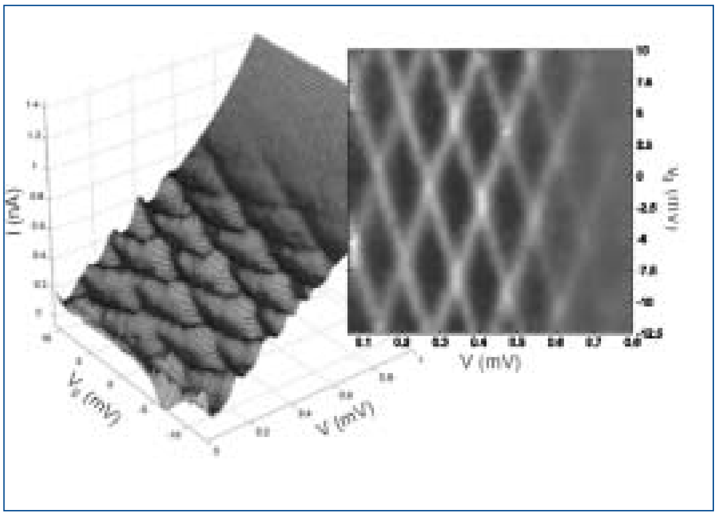

Fig. 8. IV features of an Al-Nb-Al SET, displaying gate-modulated Cooper pair resonances. The image on the right represents the current in the V-Vg plane with the background substracted. The period of the structure is set by the charging energy of the island (which was measured independently).

Rabi oscillation in coupled qubits

We have also started to investigate theoretically the quantum evolution of two-qubit systems when a microwave radiation is applied at the gate. The systems studied were a Cooper pair box capacitively coupled to a large Josephson junction (a system proposed by the

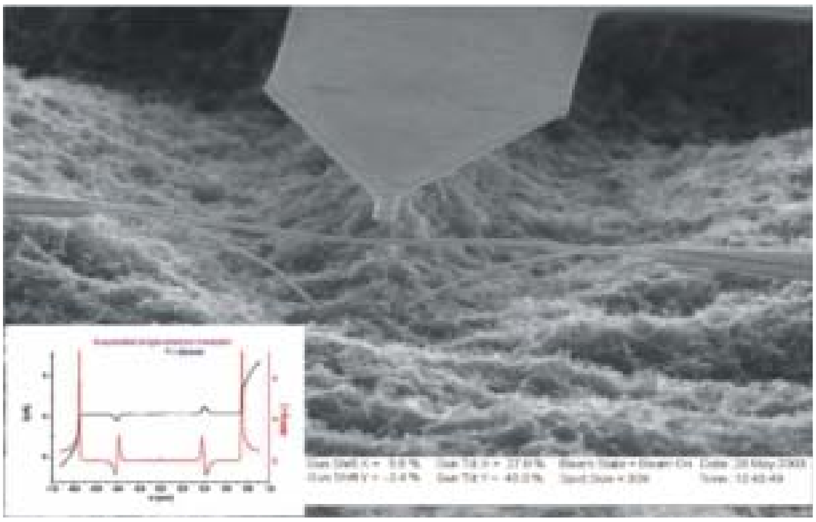

Fig. 9. The SEM picture of a SUSET. The gate electrode points to the island, which is held above the substrate by the junction themselves. The two lines pointing downward are the usual by-products of the two-angle shadow evaporation. The inset shows the IV and dI/dV of this structure, with perfectly defined Josephson, JQP, and quasiparticle currents.

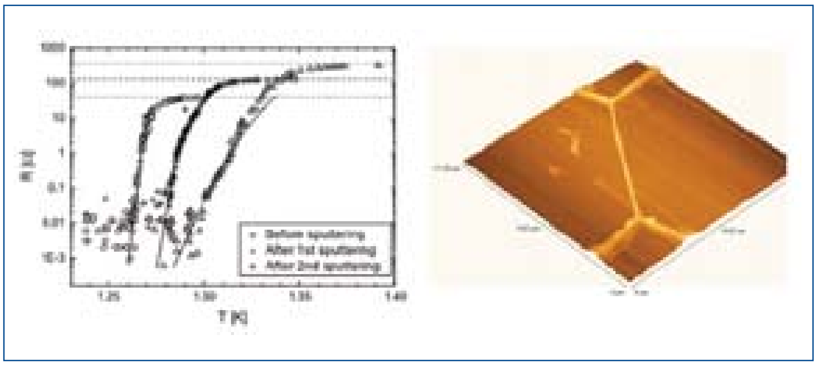

Fig. 10. Left figure shows R(T) dependency of an aluminum nanowire before and after sputtering. Solid lines are the theoretical fit according to LAMH model. Right figure shows an AFM image of a typical nanowire.

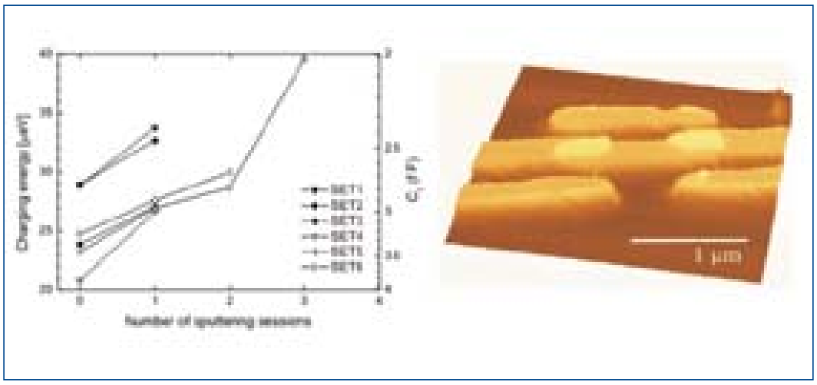

Fig. 11. Left figure shows the charging of SET as a function of sputtering sessions. Right hand side figure is an AFM image of a typical SET.

Grenoble group to study entanglement) and two capacitively coupled Cooper pair boxes (the NEC two-qubit). In both cases, we have developed a theory of Rabi oscillations that takes into account the coupling of the two qubits. In the first case, the system is analog to a laser-driven two-level atom in a QED cavity: there is a permanent exchange of quanta between the m.w. field, the Cooper pair box, and the junction, which leads to Rabi oscillations of various amplitudes. In the case of the NEC two-qubit, the quantum state can be manipulated by applying simultaneously two m.w. fields, of different frequency, at the gates of the qubits.

Fabrication of superconducting nanowires and SETs

The team led by Dr. Arutyunov in collaboration with the material science group (Dr. V. Touboltsev) has developed an ion beam based dry etching method for progressive reduction of the dimensions of prefabricated nanostructures. The method has been succesfully applied to aluminum nanowires and aluminum single electron transistors (SET). The method is based on removing of material from the structures by exposing them into energetic beam of Ar ions. The electrical measurements together with sample imaging with atomic force microscope (AFM) and scanning electron microscope (SEM) indicated that the dimensions, i.e. the cross-section of nanowires and the area of tunnel junctions in SET, were progressively reduced without noticeable degradation of the sample surface.

Fig. 12. Scratches on polycarbonate plowed by an atomic force microscope tip. The bottom width of the grooves is about 20 nm.

The reduction of the cross-section of an aluminum nanowire manifests itself as the change of the shape of the super-conducting transition R(T). Application of the Lamber-Ambegaokar / McCumber-Halperin (LAMH) model to the results confirms the reduction of the wire cross-section (figure 10). It was possible to reduce the wire effective diameter down to ~ 25 nm, starting from ~ 60 nm.

The charging energy of the tunnel junctions in SET was measured at 4.2K after each sputtering session. The increase in the charging energy as a function of sputtering sessions indicated that the tunnel junction area was reduced. Results for SETs are shown in the figure 11.

Nanolithography

For the enhancement of interdiciplinary research along with the progress of Nanoscience Center, a team under the direction of Dr. Lindell has strengthened the research efforts on nanofabrication methods to meet requirements of bottom-up fabricated nanomachines. Bottom-up refers to synthesis of nanodevices from individual molecules or atoms exploiting biomolecular and supramolecular chemistry, fluidic self-assembly and surface tension and on hydrophilic and hydrophobic surfaces. Planar electrode systems with narrow gaps are needed to electrically connect these devices into the outer world. We have intiated efforts to fabricate multielectrode accesses with sub 5 nm gaps for intra or intermolecular nanocircuits. The fabrication includes electron beam lithography, atomic force microscopy and etching. Also combination of these traditional top-down methods with micro contact printing and microfluidistic self assembly is under investigation. This work is performed in close collaboration with the microbiology groups.

Nanoelectronics and nanotechnology

Päivi Törmä

DNA sensor (Jussi Toppari, Sampo Tuukkanen)

Electrical properties of double helical DNA have been studied widely, but the controversy over experimental results still remains. Proposed charge transfer mechanism of double helix structure (fig. 1) is highly sensitive to single nucleotide mismatches. This property could be used in sequence-selective recognition of nuclear acid sequences.

We are developing a nanoscale sensor which electrically monitors the forming of double helix structure between two separated gold electrodes. Since DNA-based pharmacological methods are becoming popular, fast and simple DNA sensor has obvious applications in biological and medical analysis. This sensor can also be used for studying the conductivity of DNA giving essential information related to its potential use as a component of future electronics.

Suitability of different fabrication and measuring techniques has been studied. Electron beam evaporation is used for thin metal film deposition. Plasma Enhanced Chemical Vapor Deposition (PECVD) equipment has been supplied for the deposition of high quality insulator films. Reactive Ion Etching (RIE) and wet etching are

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Jari Salmela, graduate student
Esa Tarkiainen, graduate student
Sampo Tuukkanen, graduate student
Tommi Hakala, MSc student
Marcus Rinkiö, MSc student
Tarmo Suppula, MSc student

The group belongs to the NanoScience Center (NSC) of University of Jyväskylä.

Fig. 1. Electrical conductivity of double helical DNA. Charge transfer mechanism through the helix structure is probably based on tunnelling between Guanine-Cytosine base pairs.

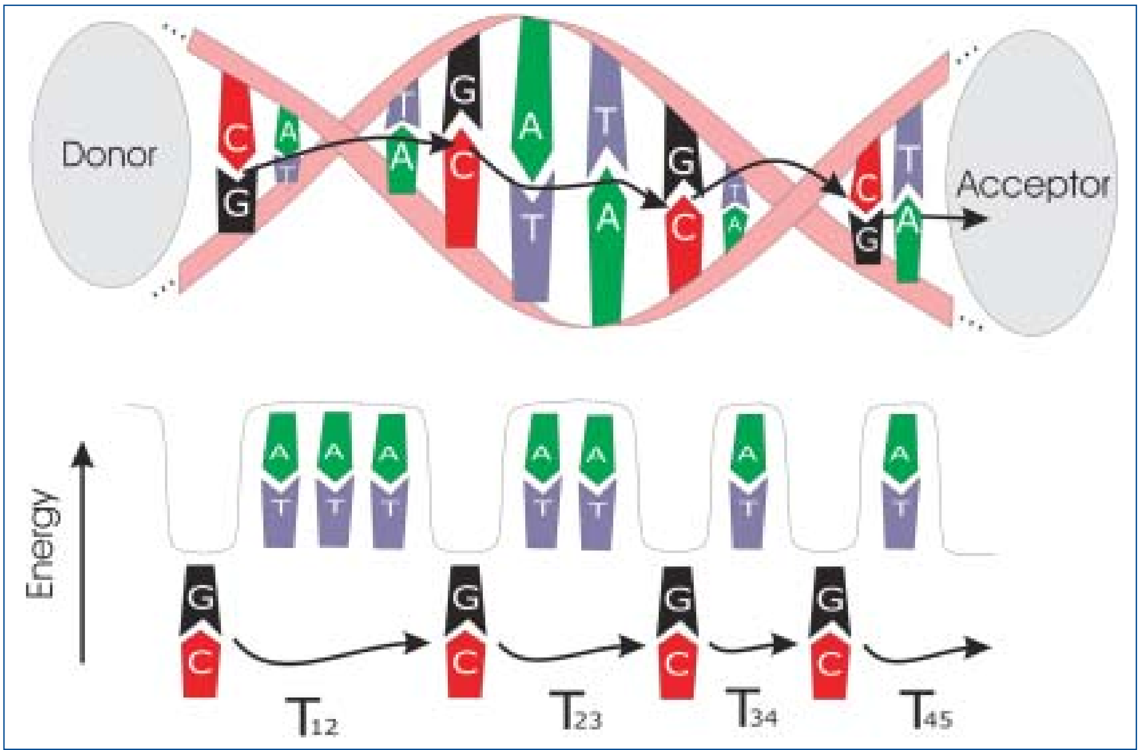
used in patterning the sensor structure.

Preliminary studies have been made concerning electrically controlled selective coating of gold electrodes with mixed monolayers of oligonuc-leotides and alkanethiol passivation molecules. Labeling of DNA is done using self-made gold nanoparticles which can be observed using electron microscopy. Voltage between the gold electrodes is applied for guiding the oligo-nucleotides (fig. 2).

This project is done in collaboration with chemists and biologists at NSC.

Nanoscale temperature sensor for bio-applications (Tommi Hakala, Tuula Jalonen)

The aim is to develop nanoscale temperature sensor, where the small size, thermal mass and sensitivity allow monitoring of temperature changes of microscopic biological systems. We have designed and tested sensors based on both metal-oxide-metal and Schottky junc-tions. Biocompatibility of the materials was studied by using the feline kidney cell line (NLFK) to test cell survival on the designed samples. Finite element method



(FEM) simulations have been carried out to estimate the temperature change due to activation of the system and to optimize the sensor structure for maximum resolution. The project is done in collaboration with biologists at NSC and industry.

Sensors for magnetic field and electric current *(Ossi Partanen, Jari Salmela)*

Microelectronic sensors for measurement of magnetic fields and electric current were developed. We have compared different sensor types and manufactured for example Hall effect-based and flux gate sensors. Finite element method (FEM)–based design software was used to run complex 3-D simulations to ensure that the miniature sensors will meet the requirements.

Prototypes were fabricated using electron beam lithography. In the final version of the sensor, the low temperature co-fired ceramic (LTCC) process was used to integrate the sensing elements into one LTCC-package together with the measuring elec-tronics. The sensor is capable of detecting rather weak inhomogeneous magnetic fields in the presence of a homogenous magnetic field. Because a current in a conductor produces a (inhomo-geneous) magnetic field around that conductor proportional to the current, this concept can be used to measure the current. Close co-operation is maintained with local industry.

Chemical sensors

(Marcus Rinkiö, Jarmo Vanhanen)

Sensing techniques for monitoring the degradation of industrial lubricating oils have been developed. We have fabricated microelements using electron beam lithographic techniques to be used as electrodes for measuring electrical properties of oils. Optical changes of oils have also been studied in view of the design of optics-based sensing. Samples collected from field service have been used to study the degradation of oil as well as to test the microstructures and optics-based probes in order to find a correlation to the ageing of the lubricant. The research has been done in cooperation with industry.

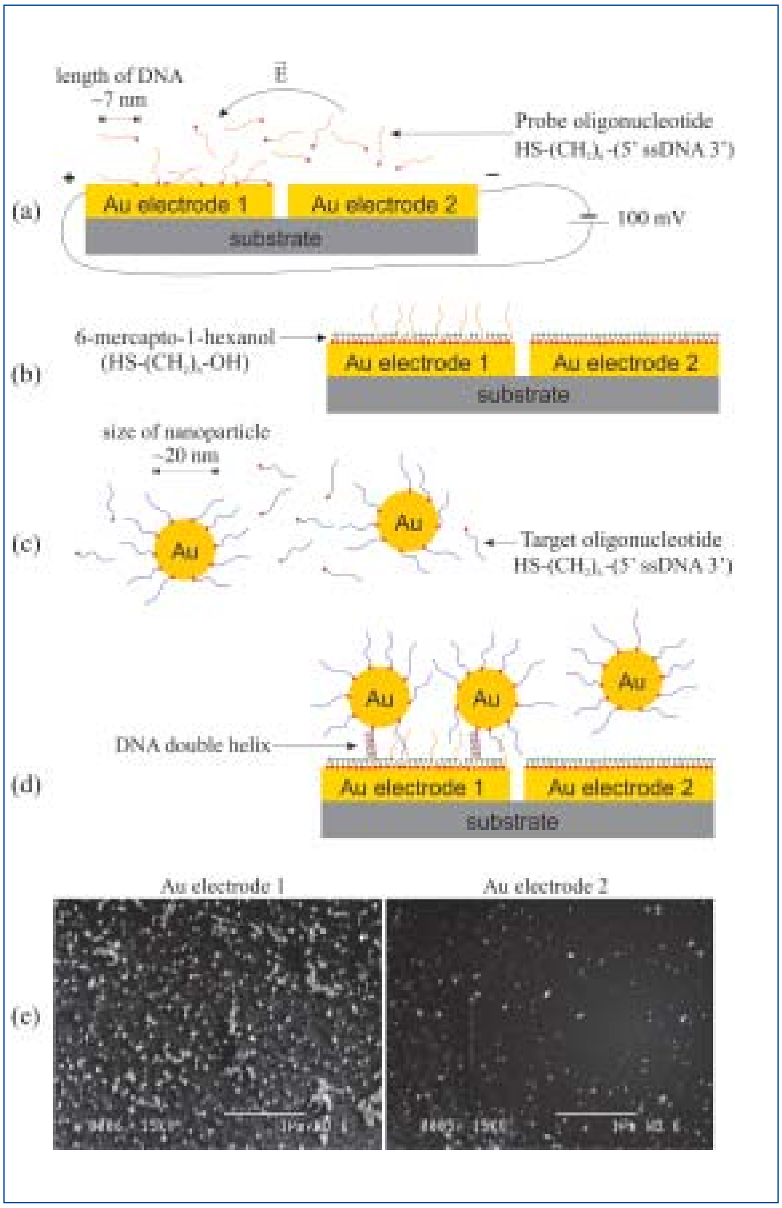


Fig. 2. Guiding oligonucleotides with electric field, DNA linked nanoparticles and mixed monolayers. (a) Thiol-modified synthetic oligonucleotides are driven to positive electrode. (b) Passivation of gold surface. (c) Complementary oligonucleotides are linked to gold nanoparticles. (d) Nanoparticles attach to the gold surface by hybridisation. (e) The sample where expected behaviour has been observed using scanning electron microscope (SEM).

Cantilever sensors *(Esa Tarkiainen)*

Microfabricated silicon nitride cantilever was used to transduce physical or chemical processes into mechanical motion. The resonance frequency of a cantilever, mounted to an atomic force microscope, changes due to mass loading resulting from adsorption of chemicals on

Fig. 3. Chemical vapour deposition and reactive ion etching equipment purchased 2003.

the surface. Adsorbed mass can be calculated with nanogram resolution by measuring the change of resonance frequency. We have fabricated gold-coated silicon nitride cantilevers to study the self-assembly of short thiolated single- and double stranded DNA on gold. Saturation time of the adsorption and surface densities of various thiolated DNA molecules have been measured.

Thermal imaging technique using microfabricated bimetallic cantilevers and atomic force microscope has also been investigated. The temperature change of the bimetallic cantilever will create static bending which is measured optically. A fabricated cantilever is mounted to an atomic force microscope in order to define temperature distribution of a sample under study.

The research was done in collaboration with the Nanophysics group at NSC.

Electron-phonon interaction in silicon at sub-Kelvin temperatures

(Pasi Kivinen)

Heat transfer in Si between the electron gas and the lattice at sub-Kelvin temperature was studied as a function of the carrier concentration. We have shown that the heat transfer process in Si has the same qualitative temperature dependence as theo-retically predicted for metals. To the best of our knowledge there is no detailed theoretical analysis of this for Si. Therefore the quantitative similarity of the heat transfer processes between metals and Si is astonishing, because in Si (contrary to metals) the Fermi surface is far from a spherical one and the intervalley scattering plays an important role for the electron transport.

Our results also indicate that the strength of the heat transfer in Si, or more precisely the material dependent constant characterizing the electron-phonon coupling, depends on the carrier concen-tration. This dependence, however, is not linear, which should be the case if the theory derived for metals were valid also for the quantitative analysis of Si. One possibility for this

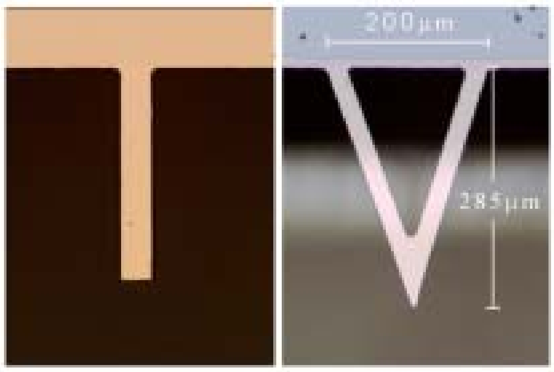


Fig. 4. Optical microscope images of a gold-coated rectangular cantilever (width: 40 mm, length: 250 mm, thickness: 1 mm) and an uncoated V-shaped cantilever.

Fig. 5. New atomic force microscope of the NanoScience Center.

phenomenon could be the intervalley scattering of electrons mentioned above.

The quantitative values of the electron-phonon coupling are at least two orders of magnitude lower than in Cu and this makes Si very promising material for certain low temperature applications, such as microsize coolers. In Si, the electron gas can be heated above the lattice temperature easier than in metals, in addition, it is also possible to tune the electron-phonon coupling, or the heat transfer, by varying the carrier concentration density.

The research was done in collaboration with VTT Microelectronics Espoo and Low Temperature Laboratory, Helsinki University of Technology.

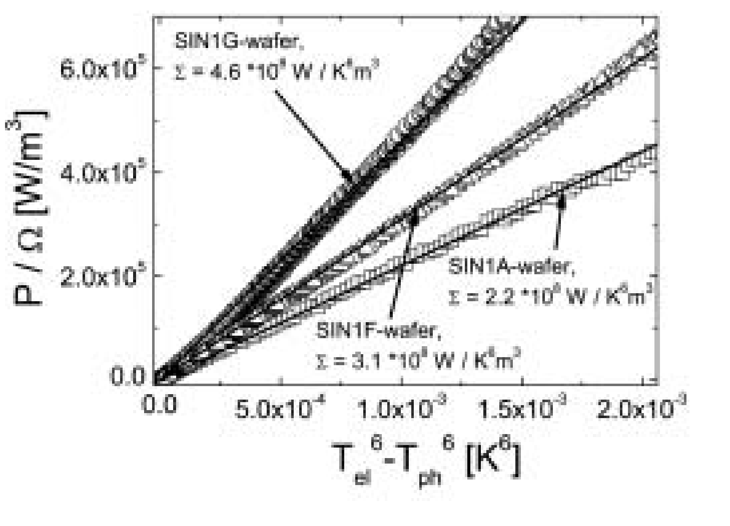


Fig. 6. The heating power density is represented against the electron and phonon temperature difference in the 6th power. The linearity of the graphs indicates that the theory derived for metals is also applicable for Si. The value for the electron-phonon coupling S can be obtained from the slope. The different carrier concentration densities are marked with SIN1A, SIN1F and SIN1G.

Cold atomic Fermi gases

(Jami Kinnunen, Mirta Rodríguez, Vesa Ruuska)

The success of Bose-Einstein condensation (BEC) in alkali gases has inspired the trapping and cooling of also the fermionic isotopes. Diluteness and the purity of atomic gases offer ideal tools for studying fundamental quantum statistical and many-body physics.

The interactions between the trapped fermionic atoms can be experimentally controlled by applying a magnetic field on the atomic cloud. The critical temperature for the superfluid BCS transition depends on the strength of the interactions. Experimentally accessible temperature ranges can be reached by using Feshbach resonances. In this strong interaction regime the gas is analogous to high temperature superconductors. Recently, BEC of molecules formed out of Fermions has been experimentally achieved by several groups, and full exploration of the strong interaction regime probably becomes experimentally feasible very soon.

Fermi gases loaded in periodic optical potential can also be used to observe purely quantum transport phenomena such as Bloch oscillations. The possi-bility of Bloch oscillations for a degenerate and superfluid Fermi gas of atoms in an optical lattice has been considered. For a one-component degene-rate gas the oscillations are suppressed for high temperatures and band fillings. For a two-compo-nent gas, Landau criterion was used for specifying the regime where robust Bloch oscillations of the superfluid may be observed. We have also shown how the amplitude of Bloch oscillations varies along the BCS-BEC crossover.

Harmonic oscillator type potentials are used to confine the alkali atoms into the optical lattice. We have also simulated the motion of the free Fermi gas in the combined potential of a harmonic oscillator and an optical lattice. Harmonic oscillator type potentials are used to confine the alkali atoms into the optical lattice, and the combined potential is an interesting system to study quantum transport. The results are in a reasonably good agreement with the experiments and show that the harmonic confining potential makes the quantum transport crucially differ from Bloch oscillations.

Fermi-Bose and Bose-Bose mixtures are one of the central topics in the field of atomic gases. We have considered the scissors mode in these multicom-ponent systems.

Photonic crystals

(Anu Huttunen, Timo Koponen)

Photonic crystals are periodic dielectric structures. The periodicity creates bandgaps for light, i.e., light in a certain wavelength region cannot propagate in the photonic crystal. The periodicity, and thus the bandgap, can be in either one, two or three dimen-sions. A typical example of a one-dimensional photonic crystal is the Bragg grating. Two-dimen-sional photonic crystals embedded with defects could be used e.g. as waveguides for integrated optics and a defect inside a three-dimensional photonic crystal can act as a microcavity. Photonic crystals are a very attractive solution to various problems in telecommunications and may be-come the key material for integrated optics.

We have studied thin slabs of one- and two-dimen-sional photonic crystals. We show that varying the boundary material results in changes in the band gap and that this effect can be utilized for reflecting light traveling along a one-dimensional photonic crystal slab by changing the boundary material abruptly. We have suggested that in two-dimen-sional photonic crystals, the same effect could probably be used for guiding of light by patterning

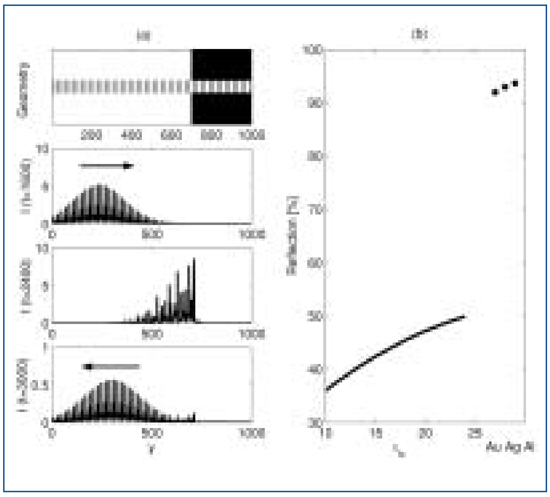


Fig. 8. (a) Energy density profiles of a Gaussian pulse in a photonic crystal slab at different times. Photonic crystal geometry is shown in the upmost part of the figure. The black areas denote GaAs and white areas denote air. The frequency of the pulse can propagate in the photonic crystal when boundary material is air, but falls into a band gap when boundary material is GaAs. This can be seen from the intensity profile as the pulse is reflected.
(b) The fraction of the energy density of a Gaussian pulse that is reflected inside the slab from the point where the boundary material above and below the photonic crystal slab changes from air to a material with dielectric constant e_b. Solid line indicates dielectric boundary materials and dots indicate metals: gold, silver, and aluminum.

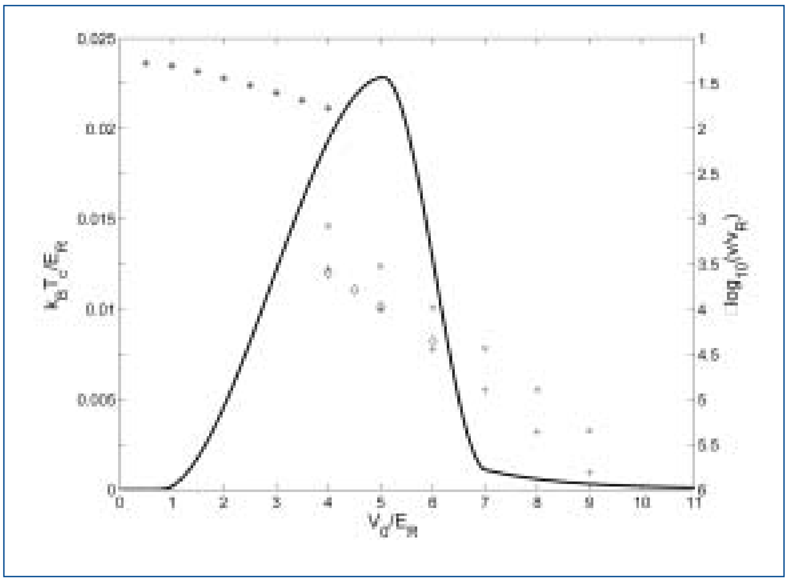


Fig. 7. Critical temperature and the Bloch oscillation amplitudes (* for normal state, other marks for superfluid) as a function of the potential depth of the sites in an optical lattice.

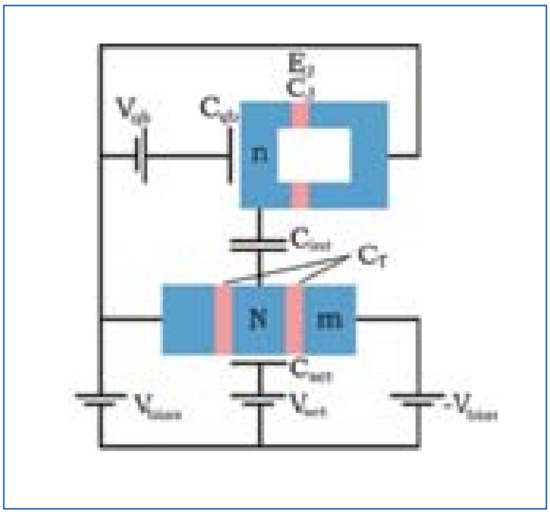


Fig. 9. The state of a Cooper pair charge qubit affects the current in the coupled single-electron transistor. Thus, the transistor can be used as a measurement device for the charge qubit by switching on the bias voltage and measuring the current.

the boundary material. We also study photonic crystal structures made of Kerr-nonlinear material.

We study coupling effects between parallel wave-guides in a two-dimensional photonic crystal. Our results indicate that the dependence of the coupling strength on the input wavelength and the distance between the waveguides is nontrivial. In some cases the waveguides can also be decoupled, which may be applied to allow minimal separation between neighbouring waveguides e.g. in integrated optics.

The research is in collaboration with Optoelec-tronics laboratory, Helsinki University of Techno-logy and VTT Electronics Oulu.

Quantum information *(Jami Kinnunen)*

Doing measurements on a quantum system reequires an interaction between the quantum level and the macroscopic detector. We have studied theoretically the use of a single-electron transistor (SET) as a quantum measurement device. A central issue is the ratio between the strength of the output signal and the backaction noise caused on the quantum system. In the cotunneling regime, the transistor approaches the quantum limit and can be used for example as a sensitive readout device for Cooper pair charge qubit. We have shown that the superconducting transistor at the threshold voltage is much more effective in measuring the state of the qubit than a normal-metal transistor at the same voltage range.

Atomic clusters and quantum dots

Matti Manninen

Clusters on surface

Car-Parrinello technique is used to study small sodium clusters on graphite surface. Three graphite layers with periodic boundary condition are used to describe the substrate and the electronic structure and binding properties of sodium clusters with 1-5 atoms are determined. In general, the binding energy of the clusters on the surface is small and the cluster geometries are close to those of free clusters in vacuum. The results suggest that open cell clusters with 3 and 5 atoms are more abundant on graphite surface than closed shell clusters with 2 or 4 atoms. Figure 1 shows the geometry and electron density of Na_4 on graphite.

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Kimmo Kärkkäinen, graduate student
Kirsi Manninen, graduate student
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Cluster melting

We have continued our study on melting of small sodium cluster using both classical and ab initio Molecular dynamics methods. Special attention has been put on

http://www.phys.jyu.fi/research/clusters/index.html

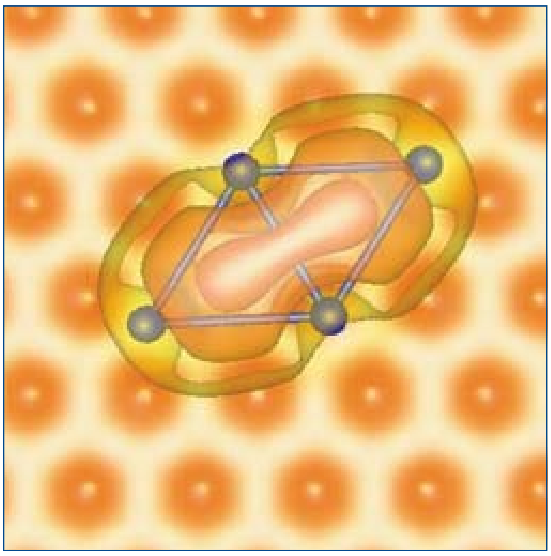

Fig. 1. Electron density and atomic arrangement of a sodium cluster with four atoms on a graphite surface.

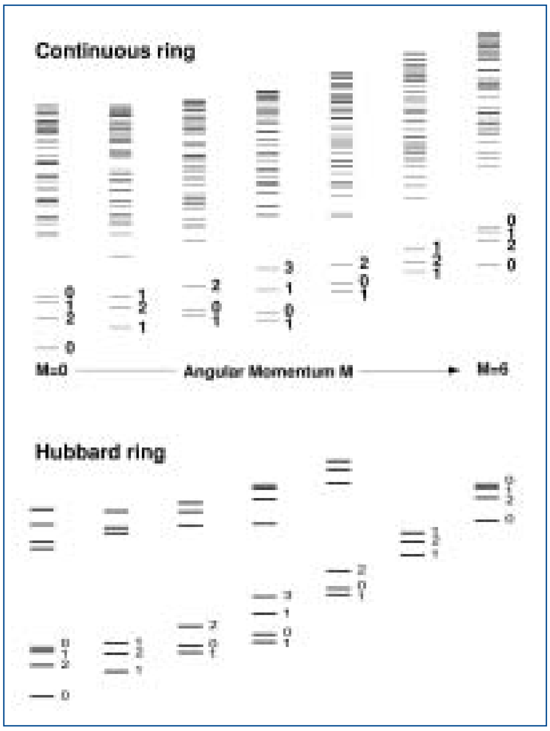

Fig. 2. Energy spectra of quantum rings with 6 electrons. The upper panel shows the rotational spectrum of a continuum ring and the lower panel the same for a Hubbard ring with eight lattice sites. The spin of each state is indicated by a number.

the melting of clusters with 58 and 92 electrons, i.e. clusters with close electronic shell. The 92 electron cluster has a clear melting transition at a much lower temperature than in the bulk. The positive ion Na_{59}^{+} interesting because it has a possibility to form geometrical packings of atoms with high symmetries. Such structures show clear electronic shell structrure but, surprisingly, turn out not to be the ground state of the cluster ion. Instead, the ground state geometry has a lower symmetry but the surface layer of atoms is more spherical. The calculated photoemission spectrum is in good acreement with the experimental result.

Multicomponent density functional theory

Local density approximation is extended for semiconductor nanostructure with several band minima. This allows applications for vertical double dots and for dots with heavy and light holes. The preliminary results indicate that the increased internal degree of freedom ("isospin") leads at densities to a generalization of Hund's first rule. At low electron densities the increased number of degrees of freedom helps the electrons to form a Wigner lattice.

Quantum rings

Exact diagonalization techniques and simple model Hamiltonians are used to study the rotational spectra, persistent current, and thermodynamical properties of small quantum rings. The results show that the periodicity of the persistent current changes from f_0 first to $f_0/2$ and eventually to f_0/N when the ring gets narrower. We have shown that the Hubbard model for discrete strictly one dimensional ring with finite U give the same rotation-vibration spectrum of "localized electrons" as the exact continuum model for a quasi-one-dimensional ring, as demonstrated in Figure 2.

Soft condensed matter and statistical physics

Jussi Timonen and Markku Kataja

The main areas of research in this group were fracture of brittle materials, dynamics of interfaces, and flow in porous media and multiphase flows. Applications were mostly in paper science and bone research.

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Markku Kataja, professor
Juha Merikoski, lecturer
Jan Åström, senior researcher -30.4.
Antti Koponen, senior researcher (part time)
Markko Myllys, postdoctoral researcher
Urpo Aaltosalmi, graduate student
Jari Hyväluoma, graduate student
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Tomi Kemppinen, graduate student 1.7.-
Riku Linna, graduate student
Raimo Lohikoski, graduate student –30.9.
Jani Maaranen, graduate student
Jussi Maunuksela, graduate student –31.8.
Lasse Miettinen, graduate student 1.9.-
Petro Moilanen, graduate student
Otto Pulkkinen, graduate student
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Esa Rehn, graduate student
Amir Shakib-manesh, graduate student –30.9.
Juha Vinnurva, graduate student

Elasticity and fracture of disordered materials

Our previous work on a dynamic rigidity transition, and on the role of connectivity in the elasticity and porosity of fibrous structures and random packings, were successfully completed. The main emphasis of the work in this research area concentrated however on fragmentation of brittle materials. We designed and implemented a parallelised numerical algorithm to model dynamic fragmentation of a 2D brittle disordered material without introducing any external constraints when imposing loading conditions. The method was verified to fulfill the static and dynamic conditions necessary for realising true fracture dynamics. With this method we were for the first time able to investigate inherent features of fragmentation without potential predominance of external constraints. We also introduced a crack branching and merging scheme in combination with a Poisson process related to the initial formation of cracks induced by external loading. This model is operative in any dimension, and can explain the widely observed shape of the fragment size distribution: a power-law contribution in the small fragment-size regime followed by a more or less exponential contribution for increasing fragment size. The fragment-size distributions resulting from our simulations conformed closely with that of the introduced model. The model distribution was as well shown to reduce in a realistic limit to the Gaudin-Schuhmann distribution which has traditionally been used to describe the fragment-size distributions found in mining industry. In collaboration with Swedish and Danish research groups, the fragment-size distribution predicted by the model was compared against those found by large-scale rock-blasting tests in the Bårarp quarry in Sweden and by fragmenting gypsum discs with varying impact energy in Denmark. The results of both sets of experiments could well be explained by the model. The fragment-size distribution from the quarry-blasting tests is particularly important as the sizes measured extend over twelve orders of magnitude. With the new software we finally began to analyse the time evolution of the fragmentation process. This on-going work addresses in detail the roles of the distinct mechanisms which form the backbone of the proposed model.

Dynamics of interfaces

We continued our work on the effect of a thin columnar defect on a propagating interface. The control parameter of the problem is the difference in driving in the defect and elsewhere in the medium. We analysed this problem experimentally using slow-combustion fronts in paper, and numerically by simulating a totally asymmetric simple exclusion process (ASEP) with a slow or a fast bond. There is a direct mapping from ASEP models to propagating interfaces of KPZ type. For large enough excess driving in the defect, the slow-combustion front develops a triangular shape with a height that depends linearly on the control parameter. This effect on the front is a direct consequence of a KPZ type of nonlinear term in its equation of motion. The triangular shape of the front is also related to its increased average velocity. In contrast with some previous theoretical and numerical results, this increase was found to disappear at a non-zero positive value of the control parameter. We therefore analysed the problem in terms of the related ASEP model. This model also displays a transition at a non-zero value of the same control parameter very much in agreement with the experimental findings. In contrast with a general belief based on results for the directed polymer problem, this transition in the ASEP model is of second order. The ASEP model predicts in addition that there are nontrivial power-law corrections in the front profile both above and below the transition, away from the defect. The exponent in the power law is different in the faceted phase above the transition and in the non-faceted phase below the transition. Furthermore, there is a change in this exponent when the control parameter changes sign, i.e. when driving in the defect becomes reduced (corresponding to a fast bond in the ASEP model). This work included collaboration with the University of Washington in Seattle.

For understanding better the 'anomalous' short-range dynamics of slow-combustion fronts in paper, we had already earlier introduced direct numerical solution of the KPZ equation with a noise term determined from beta-radiographs or optical scans of paper samples. Within this approach we could establish in detail that the short-range apparent scaling behaviour of slow-combustion fronts, and the crossover to their asymptotic KPZ behaviour, are in most part determined by the quenched disorder in the samples. Dynamical effects influence the amplitude distribution of the effective noise at short times and the apparent multi-scaling of correlations at short range. Well above the pinning transition the spatial crossover scale is determined by the spatial correlation length related to the quenched disorder, but there is also another length scale in the problem, which is related to distance to this transition. The latter length scale dominates the crossover scale close to the transition. Our previous work on the spatial and temporal persistence of slow-combustion fronts in paper was successfully completed. The stationary temporal and spatial persistence exponents were asymptotically found to agree with the predictions based on front dynamics in the KPZ universality class. Recently we started to analyse the distributions of height fluctuations of these fronts, for which exact analytical results have become available.

We also continued our work on interacting particle systems with stochastic dynamics. Special emphasis was now on condensation phenomena observed in the zero-range and related processes. Decompositions in terms of independent variables were used to obtain the stationary properties of graph-valued extensions of these processes. Particular attention was paid to matters of connectivity and effects of clustering due to the underlying particle system. Numerical simulations were employed to confirm the validity of the analytical results and to study zero-range processes in disordered geometries.

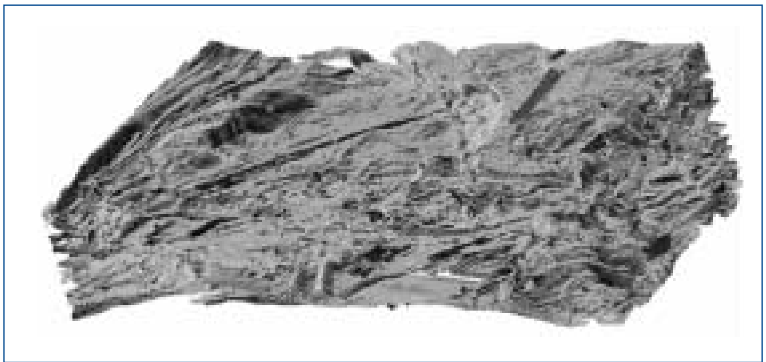


Fig. 1. An x-ray tomographic image with 0.35 μm resolution of a paper sample as obtained by the phase contrast method at ESRF, Grenoble. The dimensions of the sample are 0.18 mm x 0.13 mm x 0.41 mm. (Image by Øyvind Gregersen, PFI, Norway)

Flow in porous media

A 3D lattice-Boltzmann method was used to compute the flow resistance and other flow-related material properties of paper and paper-making fabrics. The 3D porous structures of these materials were first obtained by X-ray computed tomographic imaging of a selection of samples. Two different methods of imaging were used. Microtomography is based on absorption of x-rays produced with an ordinary vacuum tube, and its maximal image resolution is 2 μm. More sophisticated imaging techniques are available at the European Syncrothron Radiation Facility (ESRF) where coherent syncrothron radiation is used together with the phase contrast imaging method. The maximal resolution obtained at ESRF is 0.35 μm. Both these methods were utilized via an international collaboration involving Norwegian University of Science and Technology, Ecole Française de Papeterie et des Industries Graphiques and the University of Minnesota. Figure 1 shows a high-resolution image of a paper sample. The permeability value calculated for this particular sample using the lattice-Boltzmann method is $3.6 \cdot 10^{-15}$ m^2, which is very close to the typical experimental value for the same paper grade. In this way we analysed the dependence of permeability on structural properties of paper and board, and on the resolution of the tomographic image.

We also performed a 3D lattice-Boltzmann simulation of intrusion of non-wetting liquid into an X-ray tomographic reconstruction of a sample of paper board. Simulation mimics in a detailed manner the experimental mercury intrusion porosimetry, widely used to obtain the pore-size distribution of porous materials. We compared simulation results with those of a mercury intrusion measurement on the same sample and with those obtained from an image analysis of the same tomographic image. Simulation results are in good agreement with the experimental ones when the data are analysed in exactly the same way in both cases, as in evident from Fig. 2, but differ from those obtained by image analysis. Our results indicate the existence of the so-called ink-bottle effect, which affects the reliability of results of mercury intrusion porosimetry. Interpretation of the mercury intrusion porosimetry data is based on the Washburn equation and on the assumption that all pores are equally accessible. The ink-bottle effect arises in real porous materials as there are (large) pores which can only be accessed through smaller ones. Therefore, mercury intrusion porosimetry overestimates the number of small pores (underestimates the number of large pores) at least in the paper like materials

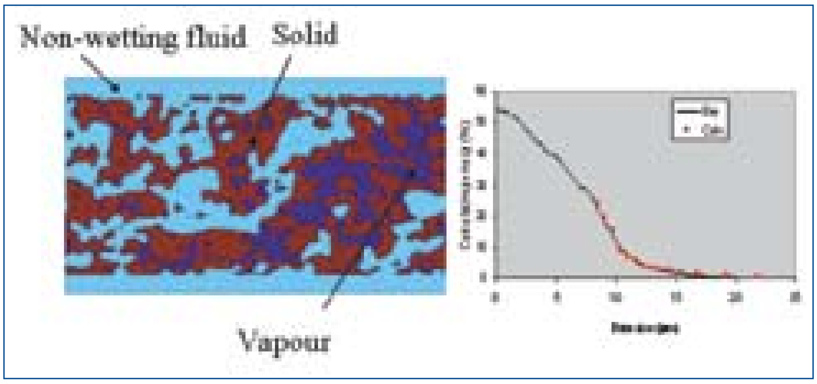
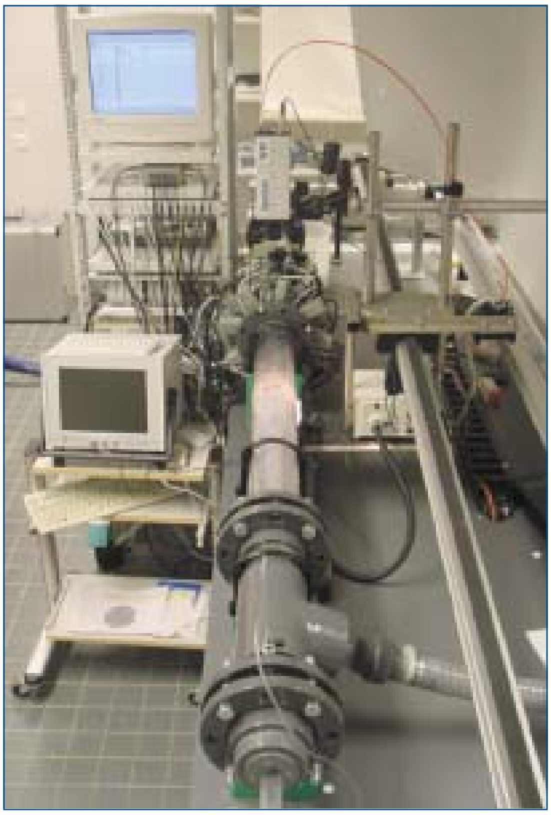


Fig. 2. A snapshot of the intrusions of a non-wetting liquid in a tomographic reconstruction of paper board and the simulated and measured (by mercury intrusion porosimetry) cumulative pore-size distribution of the same sample.

analysed here, but we expect this to be true also more generally.

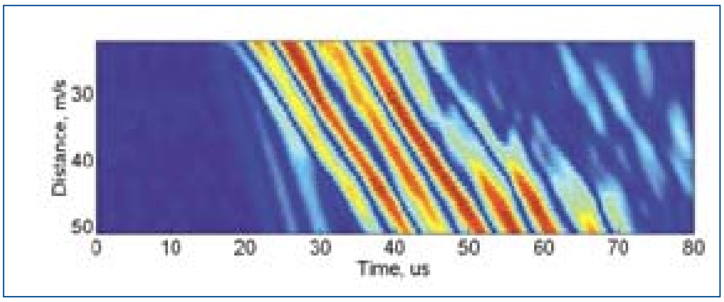
Properties of suspension flows

We developed a high speed optical tomography measurement device which has direct applications in e.g. process industry. The first application will be on-line construction of 3D density maps of suspension flows. For mapping the density distribution of the medium, both the absorption and the scattering coefficient of incident light, which is assumed to undergo diffusive scattering, can be used. Our system includes 16 lasers as light sources, and the intensity of light emitted by each laser separately is measured with 16 sensitive detectors in contact with the surface of the medium. The measured data thus comprise a 16x16 light transmission matrix from which we can reconstruct a discrete 3D image of the local absorption or scattering coefficients. The reconstruction algorithm is developed at the University of Kuopio, and is based on an ill-posed nonlinear inverse problem. In order to render the problem solvable in practice, our light detection utilizes a very sensitive lock-in amplifier technique, which makes it possible to detect signals below the average noise level. Our optical tomography device reproduces well the density map of a stationary medium, and, at the end of the year, it was installed for the first time in a laboratory scale pump line used at VTT Processes for fibre suspensions. Preliminary results for this kind of non-stationary media look promising.



Optical tomographic device mounted on a pump line for fibre suspensions at VTT Processes

The effects of particle size distribution and colloidal forces between the particles on the rheology of particle suspensions were analysed by experiments which were done in collaboration with the Åbo Akademi University. We also analysed the effects of an electrolyte and the concentration of the suspension on the viscosity of the suspension. Based on the results obtained, it is evident *e.g.* that increasing electrolyte concentration increases dramatically the viscosity of the suspension. The development of the 3D lattice-Boltzmann method for liquid-particle suspension simulations was continued so that (colloidal) forces and a size distribution of the suspended particles can now be included also in the simulations.



The colour-coded intensity of an ultrasound signal detected in a bone sample as a distance (between transmitter an receiver) versus time plot. Two different ultrasound modes are clearly visible as propagating wave fronts.

A shear flow of particle suspension was analysed by lattice-Boltzmann simulations for the effect of particle clustering on viscosity. The size distribution of the clusters formed is scale invariant in the small-cluster regime which extends to a characteristic length scale. In the small Reynolds number regime this clustering length scale determines the viscosity of the suspension, and it diverges at a jamming transition. Very recently we began to apply lattice-Boltzmann simulations to the strain-hardening effect observed in parallel-plate viscometers. According to our preliminary results, also this effect arises from a change in the intrinsic structure of the suspension such that suspended particles form instant clusters.

Flows of fibre suspensions often exhibit a regime in which the pressure loss surprisingly decreases with increasing flow rate. This drag reduction phenomenon has qualitatively been explained by formation of a thin lubrication layer of pure water at the pipe wall. We used a novel laser-optical method to measure the thickness of this lubrication layer for birch and pine fibre suspensions with mass concentrations of 0.5%-2.0%. At the same time we measured the velocity profile of the suspension with a pulsed ultrasound Doppler method. For low flow rates the velocity profile of the suspension is that of a typical plug flow. For increasing flow rate a wall layer is formed at the onset of drag reduction, and its thickness increases thereafter with increasing flow rate. Eventually the shear stress on the network of suspended fibres becomes high enough to fluidise the connected network structure in an annulus next to the pipe wall. The velocity profile of the suspension is now more parabolic. There is a maximal wall layer thickness, which corresponds to a local minimum in the pressure loss. For still increasing flow rate the wall layer is then gradually destroyed by turbulent fluctuations in the fludised annulus, accompanied by increasing pressure loss. The observed maximum of the wall layer thickness is of the order of 0.5mm for a concentration of 0.5%, and decreases with increasing concentration.

Reduction of fluid flow resistance also appears when polymers are added even with a low concentration in a fluid. The actual mechanism of this well known effect, involving the combined dynamics of the fluid and the polymer, has however remained largely unresolved. It is a challenging problem as it is expected to involve damping of turbulence in the flow. In collaboration with the Department of Chemistry we developed novel experimental methods for measuring the spatial distributions in a pipe flow of drag reduction (DR) polymers. We found quite unexpectedly that the spatial distribution of these molecules is homogeneous, and that there is no threshold concentration for the DR effect to set in. These results strongly imply that the DR mechanism should be primarily related to the influence of individual DR polymers on the local stability of the flow field. We were also able to deduce that the spatial scale relevant to this effect is the Taylor scale. This length scale and the corresponding time scale are related to generation of turbulence in the flow. The results achieved form an important step forward in our understanding of this DR effect, and they have consequences which can be directly tested by simple experiments.

Applications in bone research

We continued our work on analysing the properties of bone by using ultrasound and on improving our low frequency axial transmission device. We measured for the first time human radius bone specimens (n=51), and performed a large series of phantom measurements to investigate the effects of soft tissue which lies on top of the bone. A series of in vivo measurements was performed on the tibia of adult women (n=67). In addition, signal processing was developed in many ways, including a novel filtering method based on utilizing the known group velocity of the particular mode to be detected, and modelling of ultrasonic wave modes in bone and in phantoms was developed further. We can now quite accurately identify the experimentally detected wave modes.

Initial results for the radius specimens show good correlation between the velocities of ultrasound modes and the cortical bone mineral density and wall thickness obtained by peripheral quantitative computed tomography. These correlations were higher for the velocity of the fundamental antisymmetric guided wave (A0) mode than for the velocity of the longitudinal wave, indicating that the A0 mode indeed reflects both the material and the geometrical properties of cortical bone. It has become clear, however, that the presence of soft tissue affects the clinical measurements. We showed that the intensity of the A0 mode attenuated rapidly and its velocity decreased slightly with increasing thickness of a layer of soft material (water or silicon rubber) on top of a solid substrate (plastic or metal plate). Also, a thin layer of soft tissue had only a small effect on the in vivo detectability of the A0 mode, and it could in fact be measured for 70% of the human subjects. We are now clarifying the details of the new filtering method and constructing an empirical model for the observed phase velocity as a function of the thickness of the overlying soft material (tissue). With these improvements we expect to further improve the sensitivity of the A0 mode in assessing bone quality.

High energy physics

Ultrarelativistic heavy ion collisions

Vesa Ruuskanen and Kari J. Eskola

The primary goal of ultrarelativistic heavy ion collisions (URHIC) is to study the strongly interacting elementary particle matter, Quark Gluon Plasma (QGP), and its transition to a gas of hadrons. Interplay between the experimental and theoretical research in this field is intense. The successful start of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven in 2000 and the anticipation of the ALICE experiment at the CERN Large Hadron Collider (LHC) in 2007 have inspired and strengthened also the theoretical work on URHIC. In the theoretical and phenomenological studies of nuclear collisions we have focused on (1) predicting the primary production by using perturbative QCD (pQCD) supplemented with the conjecture of gluon saturation, (2) studying the deconfinement phase transition by using effective theories for QCD at finite temperature and density, (3) describing the evolution of produced matter from the calculated initial state to observable final free hadrons by applying hydrodynamics, (4) obtaining hadron spectra, as well as the integrated observables from the hydrodynamic calculation, (5) studying hard pQCD processes in hadronic and nuclear collisions, and (6) calculating the thermal emission of electromagnetic signals by applying the hydrodynamical model.

This research is financially supported by the Academy of Finland. URHIC (theory) also started as a new project in the Theory program of the Helsinki Institute of Physics in 2002, in collaboration with the Finite Temperature Field Theory group (prof. K. Kajantie) at the Department of Physical Sciences, University of Helsinki. We are also in close contact with prof. K. Rummukainen (University of Oulu and CERN/TH) and the ALICE group at JYFL. Internationally, in addition to running an active visitor program and organizing meetings, we are collaborating with researchers from e.g. CERN/TH (Geneve), Nordita and NBI (Copenhagen), LAPPTH (Annecy), SdPT/Saclay (France) and the University of Padova (Italy) in Europe, and from the Lawrence Berkeley National Laboratory, the University of Minnesota, and the Iowa State University in the USA. We have very actively participated in the work and organization of the Hard Probes in Heavy Ion Collisions at the LHC theory collaboration (CERN/TH). Together with Kajantie's group, we have also participated in EU network proposals such as the I3HP Joint research proposal for Hadron Physics approved for 2004-2006.

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Vesa Kolhinen, postdoctoral researcher
Heli Honkanen, graduate student (HIP/JYFL)
Sami Räsänen, graduate student
Harri Niemi, MSc student

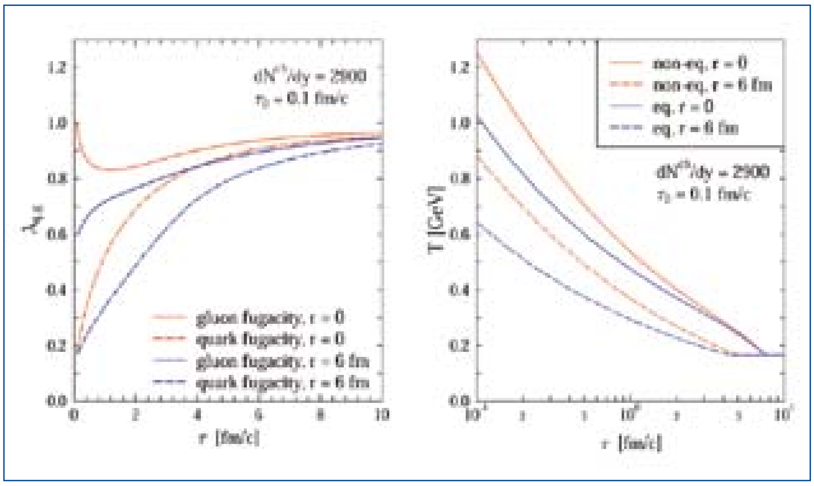
Initial state of the QGP from pQCD and saturation

Gluons and quarks with transverse momenta of a few GeV, minijets, are expected to dominate the QGP formation at collider energies. Production of such quanta can be computed using perturbative Quantum Chromodynamics (pQCD). Furthermore, infra-red safe quantities, like the transverse energy and the net baryon number carried by the minijets above a minimum transverse momentum scale, can be computed to next-to-leading order (NLO) pQCD. A further element, needed in estimating the QGP initial densities, is gluon saturation: at sufficiently high densities, gluon fusion inhibits the production of gluons at smaller momenta. A dynamically generated saturation scale of 1...2 GeV thus governs the initial parton production in central AA collisions (A(200) at RHIC and LHC. Based on the saturated minijet initial conditions and boost-invariant isentropic hydrodynamic evolution of the system, we predicted correctly the measured charged particle multiplicities for central Au+Au collisions at several cms energies at RHIC. Most recently, we have studied the chemical composition of the produced matter in detail: the initial net baryon number density leads to final antibaryon-to-baryon ratios which agree with the RHIC data. Also, initial conditions for chemically equilibrating QGP at RHIC and LHC have been computed, especially as a contribution to the CERN Hard Probes investigation.

Hydrodynamical evolution of nuclear collisions

Relativistic hydrodynamics provides a method to study the evolution of a locally thermalized expanding system. Even though the hydrodynamic results on a system of nuclear size cannot be pushed too far, strong features in its favour are the implementation of conservation laws automatically and the QCD phase transition through the equation of state. In addition to enabling the calculation of hadron spectra, it also provides a reasonably sound framework to study phenomena like electromagnetic emission or flavour evolution during the expansion stage.

We have computed the final, observable, transverse momentum spectra of different hadrons for central AA collisions within the framework of pQCD + saturation + hydrodynamics, described above. The calculations show that the low-pT part, pT≤ 3...4 GeV, of the measured pion, kaon and (anti)proton pT-spectra at RHIC are correctly reproduced. Since only a small fraction of produced particles and energy is in the spectrum at larger pT's, this demonstrates the consistency of the assumption that essentially all produced partons become thermalized. It also provides a consistent picture for the study of jet quenching: most of the partons form a thermal matter through which the high-pT partons traverse loosing part of their energy but remaining more



energetic than the partons in the thermal component. We also observe that a single, fairly high decoupling temperature Tdec=150...160 MeV reproduces the spectra of both light and heavy hadrons. This can be taken as an indication that the hadron gas phase is effectively shorter than previously expected. Encouraged with these RHIC results, predictions for the LHC and comparison with the large-pT tails of the hadron spectra obtained from pQCD are to be published soon. Related to the observed baryon densities at RHIC, rate equation network for baryon-antibaryon production has also been studied in the framework of hydrodynamical evolution. Work in progress includes studies of the decoupling dynamics, relaxation of the azimuthal and longitudinal boost symmetry in our hydro codes, and consequent further studies of asymmetric flow phenomena causing the observed azimuthal variations in the identified hadron spectra in non-central collisions at RHIC, as well as rapidity dependent observables.

The measured hadron spectra are indispensable in pinning down the space-time evolution of the system. Once the evolution is under control, one may meaningfully compute the signals from secondary collisions, such as thermal photon and dilepton production. Previously, we have computed the spectrum of thermal photons in URHIC at the CERN-SPS and, even though we are not able to differentiate between different equations of state, the results compare well with the experimental spectra. At collider energies the situation becomes more complicated, since the predicted initial (anti)quark deficit of the QGP and the evolution towards chemical equilibrium need to be considered. We have formulated this in terms of fugacities and rate equations for the quark and gluon densities in the studies initiated by the CERN Hard Probes collaboration. In the figure we show the time dependence of the temperature and fugacities at transverse coordinate r=0 and 6 fm.

Effective theories for QCD at finite temperature and density

Deconfinement and chiral symmetry restoration as function of temperature, quark chemical potential or number of flavours has always attracted much interest. For QCD with quarks, lattice simulations pose the following interesting puzzle: why, for matter in the fundamental representation deconfinement and chiral symmetry restoration appear to be linked with a single phase transition observed at a given critical temperature, while for matter in the adjoint representation there are two phase transitions, well separated in temperature? Symmetries constrain the effective Lagrangian theories, applicable to any region of the QCD or QCD-like phase diagram, whenever the relevant degrees of freedom are known. We have considered an effective theory which unifies two apparently very different sectors of a generic Yang-Mills theory at nonzero temperature: the hadronic sector and the Polyakov loop. This theory is able to communicate the information about the center symmetry of the Polyakov loop to the hadronic states which are singlets under the symmetry. Our work shows a clear and universal characteristic behavior of the singlet field, induced by the order parameter close to the phase transition. Although we explicitly consider the cases of Z_2 and O(6) symmetric order parameters, our considerations are universal and can be carried over to virtually any phase transition once the symmetries of the order parameter are identified. The basic idea is to generalize the Landau theory to include non-order parameter fields. An important application of our results is a simple and economical answer to the above puzzle. In addition to the temperature-driven phase transitions, our results are applicable also at nonzero baryon chemical potential. There are also possible future applications of our results for the equation of state used in the hydrodynamical modeling of URHIC.

Hard processes and nuclear parton distributions

Specific signals of the QGP are searched against the reference cross sections of inclusive hard processes in high energy nuclear collisions. These processes at large momentum scales, such as production of direct photons and large-mass dileptons, are computable in a factorized form if the number densities of different parton flavours in the colliding nuclei, the nuclear parton distributions (nPDFs) are known. Also in the pQCD computation of the QGP initial state the nPDFs are an essential ingredient. Earlier, we have determined the nPDFs in a lowest-order pQCD (DGLAP) analysis constrained by the experimental data of hard processes in lepton+A and pA collisions and by conservation laws. A parametrization of the nuclear effects of the parton distributions, EKS98, is publicly available also in the CERN routine library PDFLIB. As a further improvement, we are now preparing a quantitative statistical error analysis and also plan to extend the previous leading-order analysis to NLO pQCD. We have coordinated the meetings and the documentation of the physics results of the subgroup on nPDFs at the CERN Hard Probes.

As a new feature, we have studied the effects of adding nonlinear terms to the DGLAP scale evolution equations of the free proton PDFs. We predict an enhancement of the gluon number densities at small momenta at the few-GeV scales on the basis of the constraints from the recent small-x HERA data in ep collisions. Consequently, we have shown that charm-quark production at the LHC should be enhanced relative to the expectations based on the standard PDF sets. Possibilities to observe this at ALICE are also being explored. Related to the corresponding nonlinearities in nuclei, and as part of the CERN Hard Probes activity, we have reported the gluon saturation limits. These are of interest for e.g. the studies of the QGP intial densities. More detailed nPDF analysis with the nonlinear evolution equations is on our list of future work.

One of the most promising signals of the QGP, and one of the hottest topics in the field currently, is the observed clear suppression of high-pT hadrons in central Au+Au collisions at RHIC. In the absence of a medium, hadron spectra at high transverse momentum can be computed from pQCD when the nPDFs and fragmentation functions of partons to hadrons are given. By analysing the spectra measured at pp and collisions at several cms-energies, and by using the nPDFs discussed above, we have computed the high-pT hadron spectra in Au+Au collisions at RHIC. Comparison with the measurements shows a clear depletion relative to the pQCD reference spectrum in central collisions. This supports the interpretation that the high-momentum partons traverse the QGP and, indeed, experience substantial energy losses. Further studies, where the pQCD cross sections are supplemented with parton energy loss probabilities, are now in progress.

Theoretical particle physics and cosmology

Jukka Maalampi and Kimmo Kainulainen

http://www.phys.jyu.fi/research/neutrino/index.html

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Jussi Virkajärvi, MSc student

Neutrino physics

Neutrino physics is one of the most vital research areas in particle physics today. This is mainly due to the recent experimental verification of neutrino masses and neutrino oscillations via atmospheric and solar neutrino measurements. Plenty of new experiments are in operation or under planning and much theoretical work going on aiming to clarify and solve the fundamental questions associated with neutrinos and their interactions.

Our group has investigated various questions related to neutrino masses and neutrino mixing. The mass generation mechanism of neutrinos is still unknown, but the smallness of neutrino masses seem to indicate the existence of a new, so far unexplored mass scale in particle physics. Neutrinos can provide us with valuable information about this scale and the new physics related to it. Also extra spatial dimensions, which are suggested in the framework of string theories, may have interesting consequences from neutrino physics' point of view.

Two doctoral thesis works on these subjects were completed in the group during 2003 (Anna Kalliomäki and Ville Sipiläinen).

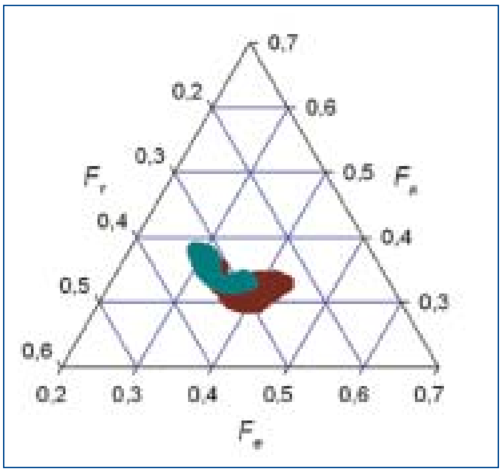
Particle astrophysics

The recent activity of the group in neutrino physics has mainly been concerned with astrophysics. One topical question in astrophysics is the origin of ultra high-energy cosmic rays (UHECR). Neutrinos, which are created along with other particles in the active centres of galaxies and other cosmic ray sources, will carry direct information about the acceleration processes responsible on the creation of UHECR. We have investigated the possible use of these neutrinos also in probing the basic properties of neutrinos and their interactions. In particular we have investigated the effects of sterile neutrinos (neutrinos that lack the standard particle interactions) on the fluxes of different flavour components of UHECR neutrinos and neutrinos from supernovae. If such sterile neutrinos were closely degenerate in mass with active neutrinos, this would be the only way to verify their existence.

The origin, acceleration mechanisms and composition of ultrahigh energy cosmic rays are unknown, especially above the so-called GZK-cutoff. Particle physics oriented models suggest e.g. decaying ultra heavy particles as sources; astrophysical candidates include gamma ray bursts and explosions of colliding binary pulsars. We have suggested a new acceleration mechanism based on quark novae. These different models have different signatures. The colliding binary pulsars or quark novae would cause a neutrino burst in neutrino detectors followed by a burst of UHECR in cosmic ray detectors like AUGER.

Cosmology

Theoretical analysis of neutrino oscillations combines field theory with intricate details of quantum measurement theory, interference and decoherence. Our group has developed formalism for studying neutrino oscillations in the early universe, and in particular in connection with the synthesis of light elements which depends sensitively on neutrino interactions and the number of light neutrino species. For certain mixing parameters oscillations between active and sterile neutrinos are shown to bring sterile neutrinos into thermal equilibrium thereby increasing the effective number of light neutrino species. It is clear from these results that the Los Alamos neutrino anomaly is incompatible with the atmospheric and solar neutrino data and the observed light element abundances. Our recent results on active-sterile neutrino oscillations employing full momentum-dependent quantum-kinetic equations have confirmed the existence of a "chaotic region" of mixing parameters, for which the final sign of the neutrino asymmetry, and hence the prediction of the primordial helium abundance cannot be accurately determined.



The predicted relative fluxes of different UHECR neutrino flavours at Earth. The green area corresponds to the standard case of three neutrinos, the blue area to the case where each active neutrino is accompanied by a sterile neutrino closely degenerate in mass.

One of the most intriguing questions in modern cosmology concerns the origin of the baryon asymmetry, excess of matter over the antimatter, in the Universe (BAU). Our group has studied the creation of BAU in the electroweak phase transition (EWPT). In the EWPT the Higgs field gains a nonzero expectation value leading to breakdown of the electroweak symmetry. For baryogenesis to succeed, it is crucial that the transition is of first order. This however is not the case in the minimal version of the standard model of particle physics (MSM), and hence we have explored baryogenesis in the minimal supersymmetric extension of the standard model (MSSM).

The dominant source for baryogenesis in MSSM comes from the CP-violation in the chargino mass matrix. The ensuing CP-violating interactions of charginos with the expanding wall cause a local bias in chargino-antichargino densities. Through collisions part of this asymmetry is transported to a left-chiral quark asymmetry (n-n)_L in front of the expanding wall. This seed asymmetry then biases the anomalous electroweak interactions (sphalerons) to create a nonzero baryon asymmetry, which then gets swept inside the expanding wall, where it is preserved because the sphaleron interactions cut off sharply in the broken phase (become much slower than H, the expansion rate of the Universe). Our results show that baryons are difficult to create also in the MSSM, but that it may be possible in a small region of chargino mass parameters m_2 and mu, which is readily accessible in the forthcoming particle physics experiments.

The quantum transport equations used in the analysis of MSSM were first derived heuristically using the WKB method. Our group has then explored the general problem of fundamental derivation of quantum transport equations for particles in nonequilibrium plasmas in spatially and temporally changing background fields. This is most naturally done by writing the field theory in the Schwinger-Keldysh closed time path (CPT) formalism. In the spatially slowly varying backgrounds and weak interactions, such as is the case in EWBG problem in the MSSM, one may simplify these equations by a controlled expansion in gradients and in coupling constant. Among our results so far is the proof that the plasma has a single particle (spectral) limit to first order in hbar, which contains the first and also dominant CP-violating effects. This result immediately leads to verification of correctness of the WKB picture. We are currently working to explore the full spectrum of CP-violating terms in the quantum transport equations for MSSM particles and their effects on creation of BAU.

Beyond the Standard Model

Supersymmetry is considered as the most natural extension of the Standard Model, and supersymmetric particles have been searched in particle physics experiments already for two decades. It is probable that first evidences of supersymmetry are not superparticles themselves but rather the indirect radiative effects caused by virtual super-symmetric particles. We have investigated such indirect effects in the framework of the Minimal Supersymmetric Standard Model. We have derived an effective Lagrangian that includes new types of interactions of the top quark and Higgs boson, not present in the Standard Model, arising from radiative effects involving supersymmetric particles. Through measuring the processes based on these new interactions it would be possible to gain information of the fundamental parameters of the MSSM.

Quantum gravity

Markku Lehto

The current interest of the General Relativity Group involves quantum gravity, especially those aspects related to discrete spacetime models. Our viewpoint is that at the fundamental level Nature should be described by a theory based on discrete structures rather than on continuous manifolds as is the case in prevailing theories. This approach raises deep questions about the structure of such a theory. For example: does 'discrete' necessarily imply the existence of a fundamental length scale, and is the exact Lorentz invariance completely lost in a discrete framework? The answer to both of these questions turns out to be negative, and this has to be taken into account when constructing a discrete

Markku Lehto, senior assistant
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model. On the other hand, we argue that any sensible physical theory should be based upon a certain set of physical principles rather than on clever mathematics alone. The search for such principles in the case of quantum gravity is extremely hard, but certainly some principles should exist, since we are dealing with a physical theory, after all.

Many familiar issues of spacetime, such as dimension, topology and metric, change drastically in the context of quantum gravity, as opposed to their meaning in general relativity and standard quantum mechanics. They become dynamical variables, and it is not clear whether we should even speak of topology and metric on the Planck scale; it may as well turn out that such large-scale familiarities are consequences of some entirely different entities functioning on the fundamental level. So, we are led to abandon most of the essential concepts in general relativity. In addition to the above-mentioned, these include the concept of a spacetime point and continuous manifolds, the most essential parts of the formulation of general relativity.

Quantum mechanics presents also deep and significant problems concerning the successful marriage of these two theories, and the reason for these problems is simple: quantum theory relies completely on Newton's view of space and time. The challenge, then, is to devise a quantum theory in which space and time emerge from the relation-ships among objects, as is the case in general relativity. One possible approach towards this goal would be to reduce quantum mechanics essentially to information theory. If this turns out to be possible, it would give strong motivation to attempt to tie all conceptual and formal aspects of the theory to information-theoretic framework. Information theory might also be the most physical framework, since all of physics is based on interactions, which are nothing but exchange of information between systems.

ALICE experiment at CERN

Wladyslaw Trzaska

ALICE

ALICE (A Large Ion Collider Experiment) is one of the major experiments at CERN LHC (Large Hadron Collider). By now ALICE involves already over 1000 physicists and technicians from about 80 institutes in 30 countries. Finland is represented by our University working jointly with the Helsinki Institute of Physics. The funding from both Institutes is roughly equal. The Finnish team is involved in 3 projects: assembly of Inner Tracker modules, T0 detector, and software. The first activity concentrates around the new Detector Laboratory in Helsinki while T0 and software development takes place in Jyväskylä. With less than 3 years left till LHC will start operation in April 2007, all of our projects are

Jyväskylä Team:
Wladyslaw Trzaska, senior researcher
Vladimir Lyapin, researcher (HIP/JYFL)
Mariana Bondila, graduate student (HIP/JYFL)

Helsinki Team:
Markku Oinonen, senior researcher
Zoran Radivojevic, senior researcher (part time)
Henri Seppänen, graduate student

undergoing a critical change that can be described as shifting from the R&D phase into the production stage.

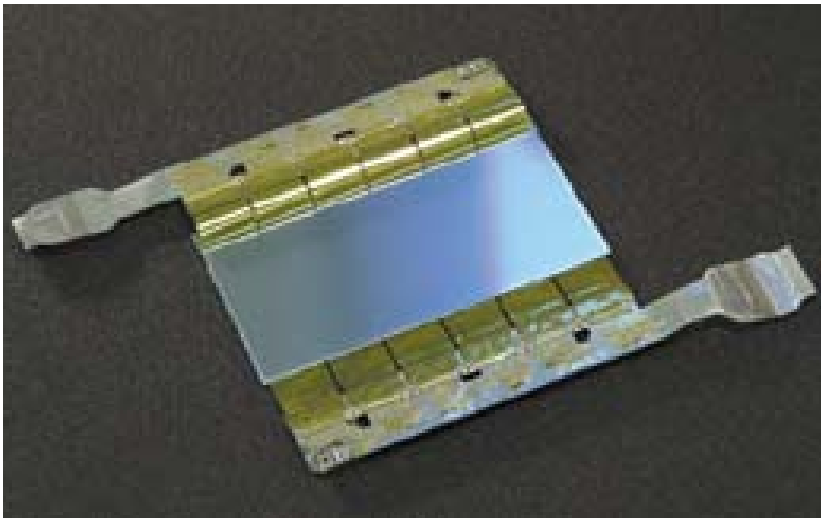
ALICE/ITS/SSD module assembly

The two largest layers of the ALICE Inner Tracking System (layers 5 & 6) will contain about 2000 Silicon Strip Detector (SSD) modules. The production of these modules is shared between France, Italy and Finland. The assembly of the Finnish share of SSD modules (about one third of all modules) will be done in the Detector Laboratory located in Kumpula Campus in Helsinki.

In the past years the entire SSD project has suffered considerable delays caused by the lack of components, redesign of the entire electronics into the use of radiation hard technology and various manufacturing problems at the commercial companies. As a result there is no contingency left within the project. It imposes on us very tight planning and demands efficient work. Fortunately we were able to keep up with the stringent schedule. By August 2003 the first two SDD modules were assembled in Helsinki and already in September they were successfully tested in-beam at CERN. Along with the prototype production for the SSD assembly, our group has addressed the reliability issues. The preliminary results indicate that our production line has a high yield and throughput and delivers lasting bonds that should endure the expected lifetime of the experiment. All in all 2003 has been very successful for our group in Helsinki. Thanks to a lot of hard work and a little of good luck we were the first Laboratory to be fully ready for the mass production of the Silicon Strip Detector modules for the ALICE experiment.

ALICE T0 Detector

T0 is one of the smallest sub-detectors in ALICE but it is also one of the few detectors that are absolutely crucial to the operation of the whole experiment. It will give the key trigger- and timing signals, measure on-line vertex position and give rough centrality. Among the many technical challenges is the total dead time below 25 μs (including digitization and readout), count rate of up to 10 MHz, required time resolution better than 50 ps, radiation hardness of up to 500 krad, operation in the 0.5 Tesla magnetic field, compact design, high



reliability and maintenance-free operation during the entire life-time of ALICE.

None of the off-the-shelf products can fulfill these requirements. Practically all of the components and in particular the entire set of front-end electronics must be custom designed and build. We have done a lot of progress in that respect. By the summer of 2003 the first prototypes of all the key electronics modules were ready for in-beam testing at CERN. Although PS beams cannot reproduce LHC conditions in which T0 will have to operate, a test in the actual accelerator environment (interference from other detectors and devices, real signals passing over the realistic lengths of cables, etc.) was absolutely essential. It was reassuring to realize that all of our components have worked well. For instance, we could reach the time resolution of 37 ps (sigma), our T0 Vertex Module prototype gave position resolution of 1.3 cm with 98% efficiency and the Mean Timer prototype gave consistent readings to within +- 10 ps.

An in-depth technical document called TDR (Technical Development Report) is an important milestone marking the end of the main R&D phase of any sub-detector of ALICE. Prior to the approval, several expert groups within ALICE and CERN review the TDR and give feedback to the research groups pointing out possible weak points in the design or scheduling. A joint TDR for all of the front detectors (including T0) is now nearing the completion. Finalizing the technical details, making the necessary Monte Carlo simulations, compiling the results of all the key measurements followed by writing the reports and editing has been only a part of this work. There is also immense challenge in designing the readout and DSC (detector slow control) for T0. We are working hard to complete the TDR in time for the March 2004 LHCC Review.

ALICE Tracking

Production of strange particles in heavy-ion collisions is one of the main research goals of ALICE experiment. In the central (head-on) collisions of lead nuclei, each accelerated at LHC to the energy of 1.4 PeV (1.4 x 10^{15} eV), one should reach, for the first time since the Big Bang, sufficient densities of quark-gluon plasma where the density of strange quarks would approach that of the light ones. This in turn should result in the boost in the production of strange particles. Unfortunately, positive identification of strange particles is very difficult. It is done, for instance, by the detection of their decay products. These products would originate not from the main vertex (collision point) but from the decay points of the short-lived strange particles and therefore slightly off the main vertex.

One of our achievements was to derive a procedure to reconstruct and identify secondary vertices. Preliminary estimations of the reconstruction efficiency and precision against the realistic background conditions are very encouraging. These methods have been developed and tested on the basis of Monte-Carlo simulations using ALIROOT (the ALICE software framework). In order to reconstruct hyperons and identify kaons via their decay topologies we look for their products in the tracking system and find the decay vertices. For that we had to develop a method of finding secondary vertices and kinematical reconstruction of the decay. Coping with the high background (high track density) resulting from the large number of particles expected to originate from Pb-Pb collisions at LHC energies is the main challenge in our work. Nevertheless, the first results, based on the detailed simulations, indicate the possibility of the successful identification of charged kaons and neutral strange particles using the Time Projection Chamber – the main tracking detector of ALICE.

Industrial collaboration

Jussi Timonen, Päivi Törmä and Ari Virtanen

The Department has numerous contacts with domestic and foreign industry and research laboratories.

In *accelerator physics* an important part in industry related research was played by radiation tests of electronics components. In addition to ESA and CERN, private companies like Saab-Ericsson Space, Hirex Engineering and Astrium Space performed their component test campaigns at the RADEF facility. Negotiations with ESA on establishing RADEF as one of ESA's test laboratories were also active during the whole year, and the signing of a contract is projected for spring 2004. This work has been carried out within the AVALI technology programme of the National Technology Agency, Tekes.

Another important branch of activities was related to medical applications. The Iodine-123 production for MAP Medical Technologies was continued at a constant level during 2003. A total of 44 production runs were performed, in which the average beam current was 340 _Ah. Collaboration with Doseco continued in terms of two MSc. projects, one of which included close collaboration with the Central Finland Health Care District. A new type of multielectrode ionisation chamber is now under develop-ment, to be used as a dosimeter device in x-ray imaging and cardiology. This work received funding from Jyväskylä Science Park through their programme for wellness technology. Yet another medical project was done in collaboration with Gammapro and Jyväskylä Radiotherapy Hospital with funding from Tekes. The aim of this long term project was to develop a new kind of g-field detector for oncology, and we succeeded to improve our position sensitive avalanche counter so as to operate in the whole accelerator voltage range of 5 to 25 MV commonly used in therapy.

Collaboration with paper and paper machine industry continued actively in terms of projects with Metso Paper and M-real. In these projects use of radiation was analysed for studying formation and element profiles in paper as well as in coating layers.

The *nanophysics* and *nanotechnology group* has well established collaboration with a few companies in Finland. For about three years ultrasensitive radiation detectors based on calorimetry and bolometric sensing for x-rays and IR-radiation have been developed in collaboration with Metorex International company from Espoo. At the first stage the work has been motivated by the need of on-chip integrable ultrasensitive sensors in space research, and collaborative projects are continuing, funded by the European Space Agency. The Nanoway company, a spin-off from the university's nanotechnology group is producing and marketing the nanothermometer invented and initially developed in our physics department. There is well defined niche market for this product and especially along with the discovery of how to extend the operation from cryogenic temperatures up to room temperature, it may well be attractive to even a wider range of customers. Nanoway also provides micro- and nanotechnical services to interested companies and institutes.

The *nanoelectronics and nanotechnology group* has established contacts with industry. The professorship in electronics has been sponsored by local municipalities and industry. The nanoelectronics group was funded by Tekes within the ELMO ("Miniatyrization of Electronics") research programme. The project focused on micro- and nanosensors and was in collaboration with the companies Enermet, Metso, Nanoway and JSP (Jyväskylä Science Park). The collaboration will be continued under new projects and including more companies interested in nanotechnology such as Nokia and Nanoscale. The Nanoelectronics Educa-tion and Investment programme is going on during the years 2002-2004 in collaboration with several companies such as Enermet, Nokia, JSP, Nanoway, Aplicom. The programme is mainly funded by EU via the regional govern-ment and partly by companies. The programme allows developing the teaching in electronics and investments to equipment essential for research in nanoelectronics and nanotech-nology. The NanoScience Center research infras-tructure programme 2004-2006, also funded by EU via the regional government and partly by companies, will be an important platform for industry collaboration in the future.

The soft condensed matter and statistical physics group continued its long-term collaboration with a number of companies in several branches of industry. The research group participated in and coordinated two large national research consortia funded by Tekes and by industry. These projects focussed on developing new experimental and numerical techniques for multiphase fluids as well as on basic and applied research on the rheological properties and dynamics such fluids. Development of experimental methods included construction of a device based on optical tomography which was successfully tested on mixing flows of fibre suspensions in the flow laboratory of VTT Processes. Pulsed ultrasound-Doppler anemometry together with an optical wall-layer measu-rement technique was used to study the basic flow properties of fibre suspensions in pipe flow. For analysing fluid flow in porous media and properties of liquid-particle suspensions, numerical simulations based on the lattice-Boltzmann method were carried out together with code development.

Several projects involved also direct collaboration with industry. These projects included experimental research, numerical simulation and modelling of processes such as paper forming and wet pressing, formation of paper, heat recovery optimisation in a paper mill, transport of fluid in coated paper surfaces, pipe flow of polymer suspensions, and construction of a new device based on acoustic resonance for the determination of bulk volume of objects of arbitrary shape. Direct numerical simulation based on the lattice-Boltzmann method was used for studying the rheological properties of particulate suspensions. In addition, this numerical technique was used for solving flow through samples of paper and paper-making fabrics such that the structure of these porous materials was resolved using high-resolution x-ray tomography. Such a combination of novel experi-mental and numerical methods facilitated prediction of various relevant transport and structural properties of these materials. Industrial collaborators in these projects included Metso Paper, Fortum, M-real, UPM Kymmene and Posiva. For getting the necessary tomo-graphic images by x-ray microtomography or by syncrothron radiation at the European Syncrothron Radiation Facility in Grenoble, international collabo-ration was initiated with the Norwegian University of Science and Technology, Ecole Française de Papeterie et des Industries Graphiques, and the University of Minnesota.

Education

Jukka Maalampi

http://www.phys.jyu.fi/teaching/index.html
http://www.phys.jyu.fi/opetus/index2.html (in finnish)

The Department of Physics offers a wide program of study in all academic levels. In 2003 about 450 undergraduates were working for a master degree, with physics, theoretical physics, applied physics, electronics, or physics teacher education as their specific major. In addition, some 50 students, mainly with a polytechnic engineer's background, studied in the master programs of industrial physics and nanoelectronics. The post-graduate studies are organized in the framework of nationwide graduate schools in condensed matter physics, nuclear and particle physics, pulp and paper science and technology, and teacher education. The number of post-graduate students aiming at the degree of Doctor or Licenciate of Philosophy in 2003 was 60. In addition to its regular teaching program, the Department has organized in co-operation with the Open University a supplementary-education program for teacher qualification, participated in by about 50 mainly engineers and unqualified school teachers. The Department has also been an active part in the Jyväskylä International Summer School, which was organized for the 13th time.

The Finnish Higher Education Evaluation Council has nominated the Department of Physics as a high-quality education unit for the period 2004-2006, the only such unit in exact natural sciences nationwide.

Student enrolment

In the summer 2003 there were 435 applicants for physics studies, with 283 indicating physics as their first choice. The entrance examination was organized together with the universities of Helsinki and Oulu. The majority of students were admitted on the basis of their high school record and national maturity test result. The Department enrolled as a whole 122 new students in 2003. About one quarter of the applicants and enrolled students were women.

Graduation

In 2003 41 students took their Master degree in the Department of Physics. The number of degrees of Doctor of Philosophy was 11. These numbers strengthen the positive trend of the number of graduations witnessed in recent years. The employment of the newly graduated students has been very good.

Educational co-operation with schools

The Department of Physics has had active co-operation with schools in Central Finland district. The popular laboratory course for talented high school students, organized now for the fourth time, collected 25 participants. The Department has collaborated with schools

also in the framework of their CERN Network by organising training lectures prior to the CERN visits of student groups. The Department has maintained its popularity as an excursion destination for school students.

The Department of Physics organized, with support of the Ministry of Education, a course of modern physics for physics schoolteachers. About 20 teachers attended this course to update their knowledge in nuclear, particle and nanophysics. The course started in 2002 and was completed with one week's study period at CERN in 2003.

Development

At the undergraduate level the Department has developed the first-year course *Introduction to modern physics,* also called "Flying start". It is a part of the program to increase students' knowledge of the local faculty, awareness of professional opportunities available for physicists, control of the progress of studies and motivation. This two weeks' crash course begins the physics studies of new students. During the course students learn about the most recent research subjects and results in physics, get to know the personnel of the Department and each other, and learn to work together in small groups.

Overall, the Department has devoted significant efforts to develop the teaching and taking it closer to the students. These include promoting teamwork and developing lecture demonstrations, as well as relating teaching to current research and industrial and other practical applications at all stages of studies. The Department also has an extensive summer student program for familiarizing students with research work.

The Flying start and the other developments of teaching have been very successful, their good effects including the reduction of the number of students quitting their studies.

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Note: ä=a, ö=o, å=a

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Markku Kataja (joint professorship with VTT)
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Theses and degrees

Theses

MSc theses
(chronological order)

Hannu Keinänen, Lukion yleisen fysiikan opiskelijoiden taidot ja käsitykset fysiikasta

Jori Halonen, SIMON-kammio

Toni Suominen, Mittauksen suunnitteluvalmius yliopisto-opiskelijoilla

Panu Koppinen, Bias and temperature dependence analysis of the tunneling current of normal metal-insulator-normal metal tunnel junctions

Tomi Kemppinen, Kartongin päällysteen kimmomoduli

Pekka Vänskä, Tuuliturbiinivaihteen kunnonvalvontajärjestelmä

Reijo Pokela, Ajettavuuteen vaikuttavat tekijät puristin- ja kuivatusosan välisessä rainan siirrossa

Merja Sinnemäki, Newtonin mekaniikkaan liittyvät tehtävät suomalaisissa ja itävaltalaisissa fysiikan oppikirjoissa

Juha Pikkarainen, Hyperspektrisen kaukokartoitusdatan analysointialgometria

Eero Kauppinen, Digitaalisen röntgenkuvauksen laadunvalvonta – sovelluksena kuvalevyt

Markus Nyman, RITU:n fokaalitason ilmaisimien testaus

Jari Kinnunen, Pintalämpötilan seurantalaite

Hannu Moilanen, Atomin optinen emissiospektroskopia

Riikka-Sisko Parviainen, Sädehoidossa käytettävien lineaarikiihdyttimien laadunvalvonta

Jani Hakala, The IGISOL cooler and trap control system

Anna-Kaisa Laesharju, Fysiikan opiskelijoiden käsityksiä valosta

Marko Manninen, Tähtitieteen perusteet

Timo Koponen, Tunneling of light in photonic crystal waveguides

Arto Takala, Jyväsjärven ympäristönmittauslautan tekniikka

Marjut Hirvi, Graafiset kuvaajat fysiikan ylioppilas-tehtävissä vuosina 1970-2001

Minna Nevala, Kohtioiden valmistus sputteroimalla ja niiden perusominaisuudet

Kristina Hedlund, Ajatuksia säteilystä ja radioaktiivisuudesta – luokanopettajaopiskelijat Espanjassa ja Suomessa

Taneli Kalvas, Ionilähdelaitteiston kehitys säteilytys-testausta varten

David Agar, Fabrication and characterization of a miniature helium-4 evaporation pot made from single crystal silicon

Laura Oksanen, Ohjelmistotestauksessa tuotetun diskreetin datan analysointi

Tuomo Pekkanen, Tyttöjen ja poikien erot fysiikan tehtävien osaamisessa

Esa Tarkiainen, Lämpötilajakauman ja massan mittaaminen mikromekaanisilla palkkiantureilla

Laura Tarvainen, Jatkuvatoimiset mittausmenetelmät kiertoleijupetikattiloiden kehityksessä

Jenni Karvonen, Elektronien ja fononien vuorovaikutuksen mittaaminen SINIS-rakenteen avulla

Tommi Eronen, Tarkat massamittaukset Penningin loukulla; JYFLin Penningin loukun ekstraktiotehokkuuden parantaminen

Antti Tolvanen, Discrete structures of spacetime

Janne Riittinen, Massalliset neutriinot ja niiden oskillaatioilmiö

Tomasz Malkiewicz, Measurements of stopping power of alpha particles using broad-range ToF-E transmission method

Markku Markkanen, Paperin formaatiota kuvaavien tunnuslukujen vertaileminen

Marjatta Salminen, Newtonin kolmannen lain opettamisen vaikeuksista

PhLic theses

Niina Nurkka, Voiman momentin opettaminen fysioterapeuttikoulutuksessa
JYFL Laboratory Report 1/2003

Juha Valve, Sädehoidon TT-simulaattori. Menetelmä, laadunvalvonta ja tarkkuus
JYFL Laboratory Report 4/2003

Jussi Ylinen, Pisaran leviäminen huokoisessa materiaalissa
JYFL Laboratory Report 5/2003

Sami Kähkönen, Elasticity and stiffness evolution in random fibre networks
JYFL Laboratory Report 6/2003

PhD theses

Jussi Maunuksela, Scaling and noise in slow combustion of paper
JYFL Research Report 1/2003

Arttu Luukanen, High performance microbolometers and microcalorimeters: from 300 K to 100 mK
JYFL Research Report 2/2003

Veli Kolhinen, Penning trap for isobaric purification of radioactive ion beams at IGISOL
JYFL Research Report 3/2003

Sami Hahto, Development of negative ion sources for accelerator, fusion and semiconductor manufacturing applications
JYFL Research Report 4/2003

Markko Myllys, Experimental realization of KPZ dynamics: slow combustion of paper
JYFL Research Report 5/2003

Päivi Nieminen, Competing structures in very light bismuth isotopes
JYFL Research Report 6/2003

Pekka Koskinen, Models for quantum dots and rings
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Amir Shakib-manesh, Flow dynamics of complex fluids using numerical models
JYFL Research Report 8/2003

Jussi Toppari, Transport phenomena and decoherence in short Josephson juntion arrays
JYFL Research Report 9/2003

Jussi Huikari, ISOL-method in studies of medium-heavy Z~N nuclei
JYFL Research Report 10/2003

Heikki Kettunen, Decay spectroscopy of heavy nuclei beyond the proton drip line
JYFL Research Report 11/2003

Degrees

(alphabetical order)

BSc degrees

(main subject)

Tommi Eronen (physics)
Terhi Hongisto (physics)
Taneli Kalvas (physics)
Tomi Karttunen (applied physics)
Jenni Karvonen (physics)
Pasi Keinänen (physics)
Timo Koponen (physics)
Markus Nyman (physics)
Mikko Pynnönen (electronics)
Antti Rovasalo (applied physics)

MSc degrees

(main subject)
*=MSc includes teachers pedagogical studies

Tommi Eronen (physics)
Jani Hakala (physics)
Jori Halonen (appl. physics)
Kristina Hedlund (physics)*
Jussi Helaakoski (physics)*
Marjut Hirvi (physics)*
Hannu Huhtala (physics)*
Jenni Karvonen (appl. physics)
Eero Kauppinen (physics)
Hannu Keinänen (physics)*
Tomi Kemppinen (appl. physics)
Jari Kinnunen (appl. physics)*
Timo Koponen (theor. physics)
Panu Koppinen (theor. physics)
Jenni-Mari Kotila (theor. physics)
Anna-Kaisa Laesharju (physics)*
Tomasz Malkiewicz (physics)
Marko Manninen (physics)*
Markku Markkanen (appl. physics)
Mikko Moisio (physics)
Minna Nevala (physics)
Markus Nyman (physics)
Laura Oksanen (appl. physics)
Ossi Partanen (electronics)
Riikka-Sisko Parviainen (appl. physics)
Tuomo Pekkanen (physics)*
Juha Pikkarainen (physics)
Reijo Pokela (appl. physics)
Jukka Rahkonen (physics)*
Janne Riittinen (theor. physics)
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Pekka Vänskä (electronics)

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Juha Valve (physics)
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PhD degrees

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