annual report 2002

JYFL

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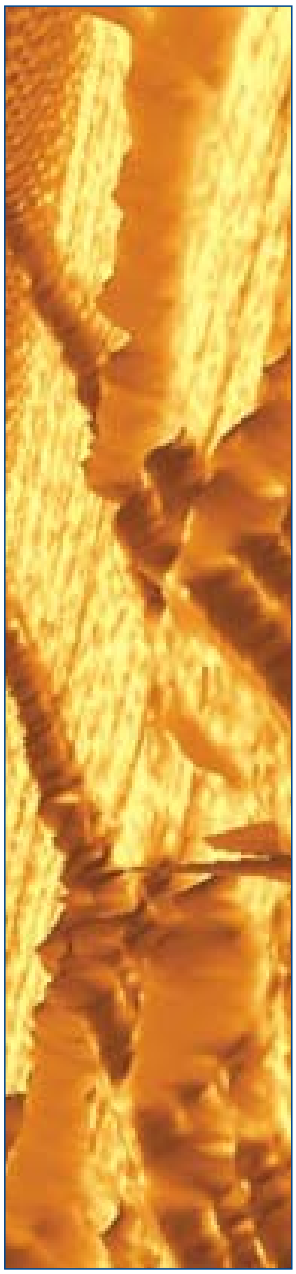

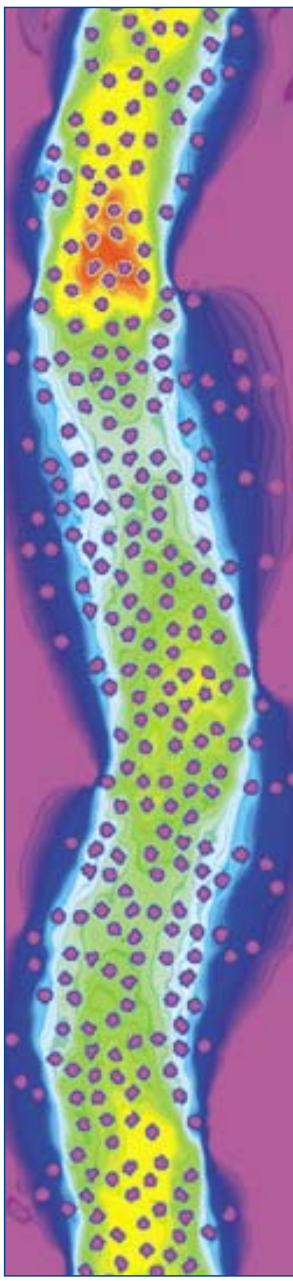

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DEPARTMENT OF PHYSICS
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Contents

Department of Physics

Matti Leino

The Department of Physics (JYFL) with its 540 students and 160 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.

Teaching

In 2002 the numbers of MSc and PhD degrees awarded in physics were 32 and 5, respectively. The Physics Department has recently been recognized by the Finnish Higher Education Evaluation Council as one of the high-quality education units in Finland. The Department participates in several national graduate schools and coordinates the Graduate School in Particle and Nuclear Physics. The Accelerator Laboratory has the status of a Marie Curie Host Training Site. The importance of developing and improving the teaching is fully recognized and more resources have been devoted to this area.

Research

The year 2002 was for most of the department the third year as the Finnish Centre of Excellence in Nuclear and Materials Physics. 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 form a new 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 at HIP.

In nanotechnology, the research focuses on nanoelectronics as well as experiments and theory of the electronic properties of micron and submicron size structures and their fabrication. Quantum coherence in small Josephson junctions is studied for finding out whether these systems can be used as elements of a quantum computer. Lithographies based on electron beam and atomic force microscopy are used in the fabrication of nanostructures.

In electronics, research focuses on nanotechnology, especially bio-nanoelectronics, and on microsensors. The theoretical studies in the electronics group have also dealt with the properties of fermion gases at low temperatures.

Research on disordered materials deals with the theory of rigidity and fracture of both brittle and ductile film like materials that can be modelled as random fibrous

Some statistical data in 2002

Personnel	160	(55)
- professors	13	(11)
- lecturers	5	(5)
- senior assistants	8	(8)
- assistants	5	(5)
- researchers and research assistants	99	(5)
- technicians	25	(17)
- administration	5	(4)
( ) = permanent posts		
Undergraduate students	538	
of which first year students	103	
Graduate students	55	
MSc degrees	32	
PhLic degrees	1	
PhD degrees	5	
Credits (national)	5696	
Number of foreign vistors	240	
Visits abroad	180	
Peer reviewed publications	118	
Invited talks	28	
Other talks	54	
Posters	53	
Seminars given at JYFL	37	
Seminars given outside JYFL	31	
Funding (million €)	8,8	
* University budget (excl. premises)	4,1	
* External funding	4,7	
- Academy of Finland	1,7	
- Technology Development Centre	0,5	
- International programmes	0,7	
- Ministry of Education	0,4	
- Contract research	0,5	
- Others	0,9	

networks in two and three dimensions. Applications will typically be in paper physics. Fluid flow in random porous structures and particulate suspension flows as well as propagation of interfaces in disordered (porous) materials have also been studied.

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.

The JYFL cyclotron delivered ion beams for nearly 6500 hours in 2002 mainly for the study of exotic nuclei and reaction mechanisms. New techniques have been developed in manipulating rare isotopes with radiofrequency quadrupole ion traps as well as high-precision Penning traps. In heavy element research studies of microscopic structures of very heavy elements such as nobelium (Z=102) are paving the way for deeper understanding of the stability of the superheavy elements.

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

The nuclear theory group develops microscopic nuclear models and applies them to nuclear spectroscopy, and to the 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.

Research

Nuclear and accelerator based physics

Summary of the Accelerator Laboratory activities

Rauno Julin

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

In 2002, the total operating time of the cyclotron was close to 6500 hours, but the beam on target hours were "only" 4852, clearly reflecting the large number of test and commissioning experiments for several new devices. A total of 36 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 ECR ion sources, especially on their extraction. High-energy heavy-ion beam cocktails have turned out to be a new useful tool in SEE tests of space electronics. The commercial production of ^{123}I with 35 MeV protons for MAP Medical Technology Ltd. has now become established.

At the IGISOL facility, the RFQ beam cooler has been successfully employed, with particular effectiveness in laser experiments. First mass measurements with the new Penning trap are very promising. The CERN-ISOLDE activity of the IGISOL group has now been established as a part of the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP).

Commissioning experiments for the new focal plane spectrometer GREAT at the RITU separator and for a new triggerless Total Data Readout (TDR) data acquisition system were successful. GREAT and TDR are designed and funded by the UK universities and represent the most valuable foreign investment in instrumentation so far at JYFL. They will play a key role in the coming tagging experiments for exotic heavy nuclei carried out at RITU, especially with the SACRED and the new JuroGam Ge detector array.

The research in the laboratory still forms an important part of the Centre of Excellence in Nuclear and Materials Physics programme of JYFL. The operation of the laboratory as one of the European Research Infrastructures in the IHP programme of EU has now been extended to the end of January 2004. 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 is playing an active role in planning 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). The accelerator laboratory now has a status of a Marie Curie Training Site of the EU, the first three Marie Curie doctoral students smiling in the photo.

The 15th International Workshop on ECR Ion Sources, ECRIS´02 was held at JYFL in June. The number of participants was 73.

A workshop focused on the use of the coming JuroGam array was held in November and gathered 50 participants from European countries.

Jaroslaw Perkowski from Lodz, Karen Van de Vel from Leuven and Audrey Chatillon from Saclay are the first doctoral students utilising the EU fellowships of the Marie Curie Training Site at the JYFL accelerator laboratory.

Accelerator facilities

Esko Liukkonen

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

Since 1993 the cyclotron has been operated about 60 000 hours, and since 1996 each year the beam time hours have exceeded 6000 hours/year. In 2002 the total operating time was 6468 hours out of which the beam was 4852 hours on target. The rest of the total time consists of stand by time caused by the user (1210 h) and beam tuning and developing. Proton was the most used ion (25%). They were used for ^{123}I production and proton induced fission (IGISOL). The second most popular beam was ^{48}Ca (12.5 %) delivered to the gas filled recoil separator RITU.

During the year 2002 the 14 GHz ECR ion source was the main injector for the K130 cyclotron.The old 6.4 GHz ECR ion source went through an upgrade of the hexapole magnetic field. The object of the upgrade was to increase the radial magnetic field using an iron cylinder around the hexapole structure, i.e by using the old permanent magnets. An improvement of about 30 % was achieved and consequently the optimum magnetic field for the microwave frequency of 6.4 GHz was almost obtained. As a result of the project an improvement of around 20 % to the performance of the ion source was measured. However, it was found also that the ion beam intensity is now limited by the extraction of the ion source.

6468 total beam hours in 2002.

In the spring 2002 the LBNL-type emittance scanner was built and assembled into the beam line of our ion sources. The measurements to understad the behavior of the emittance have been started. It has been found that the emittance value is typically between 130-250 mm mrad depending on the source tuning and the charge state. The acceptance of the K-130 cyclotron is 100 mm mrad. Figure 2 shows the emittance of oxygen ion beams as a function of the charge state.

Esko Liukkonen, professor
Pauli Heikkinen, senior scientist
Hannu Koivisto, scientist
Sami Hahto, graduate student (in 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
Sari Luodes, operator –8.3.
Hannu Leinonen, technician
Raimo Seppälä, technician

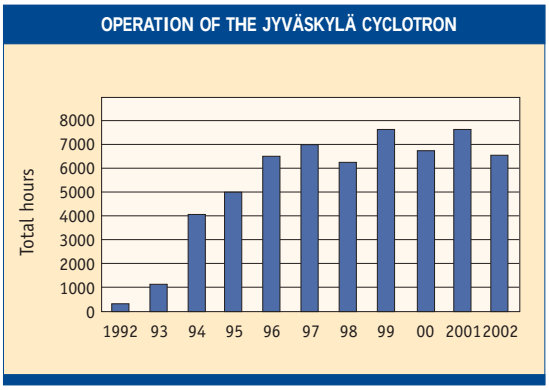

Fig. 1. Operation of the Jyväskylä cyclotron

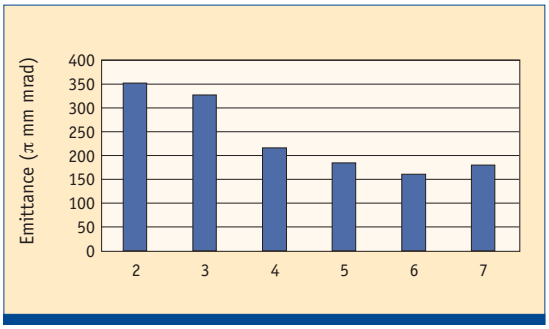

Fig 2. The emittance of the oxygen ion beams as a function of the charge state.

ECRIS'02: 15th International Workshop on ECR Ion Sources at JYFL

The 15th International Workshop on ECR Ion Sources, ECRIS'02 was held at JYFL on June 12-14, 2002. The total number of participants was 73. Seven of them were Finns and the rest represented 17 different nationalities. One half of the participants were new, i.e. they did not attend the previous ECRIS'99 workshop in CERN. The workshop covered the main topics related to the ECR ion sources, as well some of its applications in research. Titles of the presentations (see, http://www.phys.jyu.fi/ecris02/) reveal a rather wide variety of items, like reports of new sources, improvements of older sources, studies of processes related to different parts of the source and beam handling, future developments, magnet designs, and various theoretical aspects, etc.

The absolute highlight of the workshop was Dr. Richard Geller's farewell speech.

Dr. Richard Geller gave his farewell speech, "30 Years of High Charged ECRIS Development" in the ECRIS'02 workshop. The overall number of presentations in the workshop was 65, including 32 oral presentations and 33 posters. Also a guided tour of JYFL's laboratories was included in the program, as well the workshop dinner in Savutuvan Apaja with Dr. Arne Drentje's speech "Thank You for the ECRIS" to Dr. Richard Geller.

Nuclei far from stability and radioactive beams

J. Äystö and H. Penttilä

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

Our activity in 2002 has followed the well established program consisting of numerous activities in R&D on research instrumentation as well as experiments carried out at JYFL and ISOLDE, CERN. The work at ISOLDE is carried out within the Nuclear Matter Program of the Helsinki Institute of Physics. Major highlights of IGISOL have been the completion of JYFLTRAP system to include now also the Penning trap for mass measurements as well as for mass purification of isobars for nuclear spectroscopy. JYFL RFQ cooler has continued strong physics program on collinear laser spectroscopy. These experiments are carried out under the leadership of the British collaborators from Manchester and Birmingham universities.

All experiments carried out in 2002 are not discussed in this report due to the early stage of their data analysis. Such experiments include an attempt to determine precisely the electron capture branching in the decay of ^{100}Tc, performed in collaboration with the University of Notre Dame and ANL [1], and study on N = Z nuclei interesting on the astrophysical rp-process point of view, in collaboration with St. Petersburg NPI [2].

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.

Juha Äystö, professor
Heikki Penttilä, academy researcher
Ari Jokinen, academy researcher
Jerzy Szerypo, senior scientist –29.5.
Andrey Popov, senior scientist
Stefan Kopecky, senior scientist 15.3.–
Serguei Zemlyanei, senior scientist, – 30.9.
Arto Nieminen, graduate student –30.10., scientist 1.11.–
Wenxue Huang, scientist
Jussi Huikari, graduate student
Anu Kankainen, graduate student
Veli Kolhinen, graduate student
Sami Rinta-Antila, graduate student
Youbao Wang, graduate student
Jani Hakala, MSc student

Technical development

Liquid helium ion catcher. [3] The use of superfluid helium as stopping medium to convert a high-energy beam to a low energy one has been studied. After thermalization in superfluid helium, a positive ion spontaneously forms a "snowball": a cluster with helium atoms owing to electrostriction. Our current work has concentrated on the extraction of snowballs/ions from the liquid into the vapor phase from where they can be injected into vacuum for further handling and/or post-acceleration. The setup consists of the experimental cell placed inside a helium evaporation cryostat. An open ^{223}Ra alpha source was placed at the bottom of the cell and surface-barrier detector was mounted on the top. Four ring electrodes were installed in between to provide electric field. Alpha-decay recoil ions ^{219}Rn were stopped in superfluid helium, transferred to the surface and extracted by electric field into the vapour phase. Efficiency of "snowball" formation, transport in liquid helium, ion extraction trough the helium surface and transport in vapour were studied for different experimental settings (with respect to temperature and electric field strength). The efficiency for extraction across the liquid surface was 23(4)% at 1.6 K, the release time 90(10) ms at 1.5 K and the barrier for positive ions through a free superfluid helium surface 19.4(4.5) K. The pulsed second sound proved to be effective in enhancing the extraction. Extraction of positive ions across the superfluid helium has been observed for the first time.

Electric field guidance inside the HIGISOL chamber. [4] A large gas cell has a long evacuation time and, as the result, high neutralization probability. It is proposed that applying an electric field would decrease the evacuation time and neutralization losses. The earlier tests have shown mostly controversial results. In the present attempt a gas cell with an electric field has been designed and tested with a ^{223}Ra a-recoil source. The dimensions of the cell body are similar to a HIGISOL cell, except a set of three electrodes used to form and shape an electric field. In addition to the electrodes, the setup

included a tungsten coil close to exit aperture. The purpose of the coil was to compensate the space charge at the exit by emitting electrons. The gas cell efficiencies and evacuation time were estimated from the comparison of a-activity of mass-separated samples at mass A = 219 (^{219}Rn, $T_{1/2}$ = 4 s) and A = 215 (^{215}Po, $T_{1/2}$ = 1.8 ms). The obtained results show a clear effect of the applied electric field on the evacuation efficiency of short-lived ^{215}Po and essential improvement for ^{219}Rn when ions are stopped in the helium gas further than 20 mm from the exit hole. The measured ion guide efficiency for ^{215}Po increased from 0.2 % to 20 % by the applied electric field. This result is in agreement with the Monte-Carlo simulation results and has its origin in a faster ion evacuation. The effect of charge compensation also obvious but the effect shows up only after some threshold current, as seen from figure 1.

JYFLTRAP. [5] The second step in the JYFLTRAP project, the completion of the 7 tesla Penning trap system, has been realized in the fall 2002. The goal of the project was to build a high precision (R = 10^7) Penning trap for mass measurements, and a "low precision" (R = 10^5) trap for isobaric purification of ion beams delivered by the IGISOL RFQ Cooler. The construction of the mass measurement trap was completed and the final installation of electronics modules will take place in the spring 2003. The main emphasis in 2002 was laid on getting the purification trap in operation. After struggling the first part of the year with problems related to the high voltage platform and redesigning the unstable extraction system, the first radioactive ^{58}Cu ions from ^{58}Ni(p,n)^{58}Cu reactions were trapped and purified with a mass resolving power (MRP) R 70000 in N ovember 2002. In addition to radioactive ^{58}Cu ($T_{1/2}$ = 3.2 s) ions the A = 58 ion beam from the IGISOL consists of stable ^{58}Ni ions that are sputtered off the ^{nat}Ni target (figure 2). The mass resolving power R 70000 was obtain ed using a 450 ms trapping cycle. With this MRP, the mass excess of ^{58}Cu could be determined as -51674 ± 28 keV/c^2, which is in good agreement with the value -51660 ± 15 keV/c^2 from the 1995 Mass Tables. It should be noted that the design value of the MRP R = 10^5 was thus reached and in some attempts even exceeded. Figure 2 shows a mass spectrum from another test run, where the cyclotron frequency scan of trapped radioactive ions produced in 30 MeV proton induced fission of ^{238}U is shown. Also in this test a mass resolving power of approximately 70000 was reached. Furthermore, the gamma ray spectrum from the decay of a purified ^{112}Rh source was measured, proving that the isobaric beam purification works at a sufficiently high level for performing nuclear spectroscopy experiments.

Two parameters are crucial when judging the performance of the purification trap: the mass resolving power and the overall transmission. The first successful on-line operation was preceeded by a long optimisation process with stable Xe beams. For the mass resolution most of

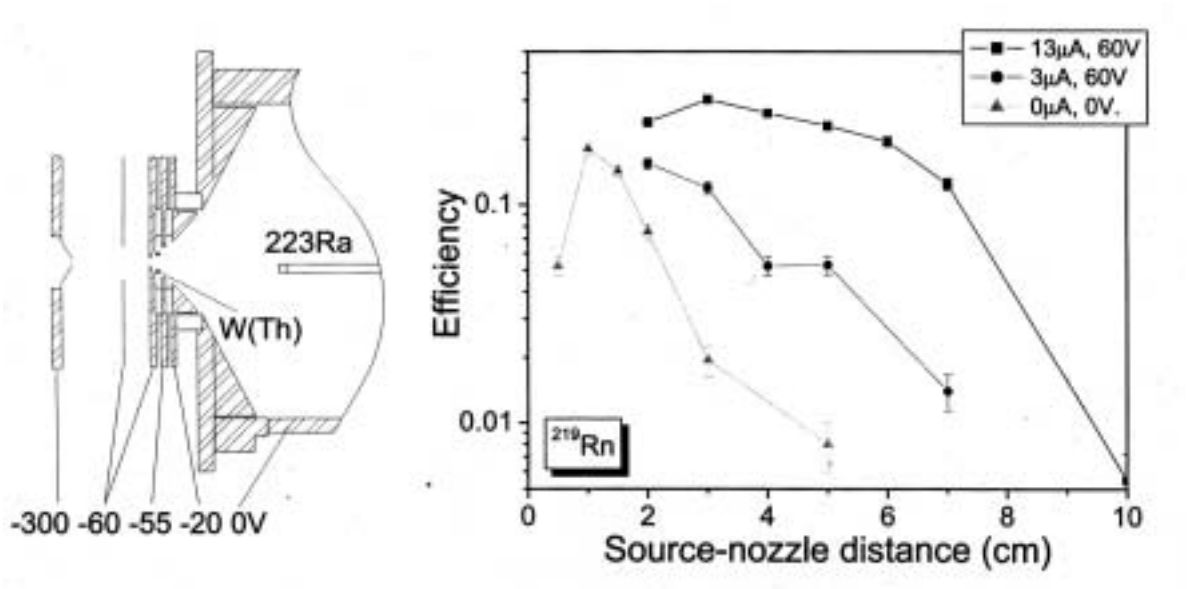

Fig. 1. Left: gas cell with electrodes. Right: the ion guide efficiencies with three different settings. The green marks show the situation with no electric fields and no charge compensation. The red curve shows the effect of applied electric field. The curve shown is measured with some charge compensation, but it does not essentially differ from situation with no electron current at all. Finally, the black marks show ion guide efficiency with the electric field and an adequate charge compensation.

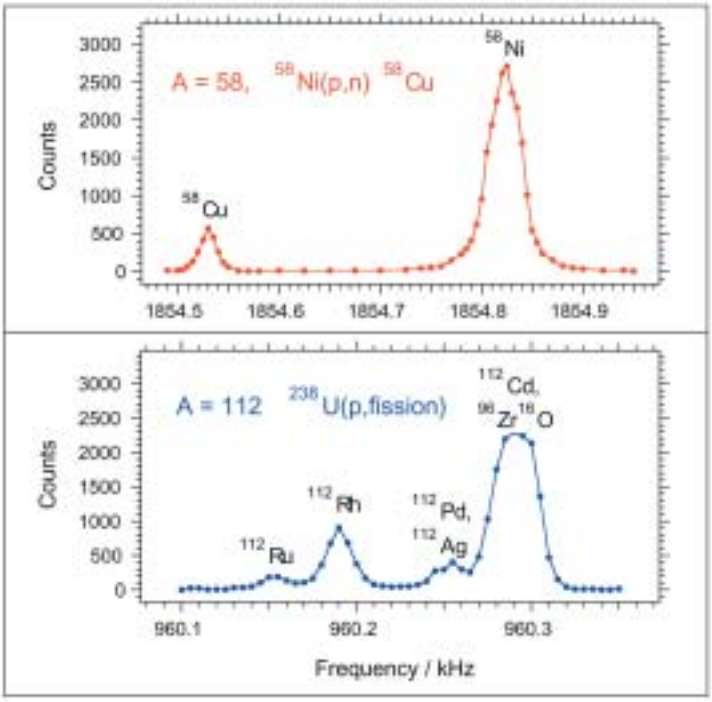

Fig.2. Upper panel: Mass distribution for mass A = 58 in reaction ^{58}Ni(p,n)^{58}Cu, E_p=18 MeV. Lower panel: Mass distribution for mass A = 112 in reaction ^{238}U(p,f), E_p=30 MeV

the work was devoted to find the correct operation parameters, i.e. to understand the interplay between buffer gas pressure, cooling times, excitation times and applied RF fields, and how to choose these parameters for obtaining suitable mass resolving powers and cycle times. A number of possible trapping schemes, varying in total cycle time and mass resolving power, were identified. The trapping cycle times varied between 160 ms and 450 ms, the obtained mass resolving powers between R = 20000 and R = 60000. For the transmission of the trap shoot trough transmissions of approximately 30% were observed. The capturing efficiency of the bunched beam from the RFQ-cooler was 60% (being lower than expected). With an improved capturing scheme, and a modified extraction system of the RFQ-cooler that allows ion extraction as considerably shorter pulses, the capturing efficiency is expected to increase up to 80% during the next year.

Highlights of physics experiments

Laser spectroscopy. [6] Laser spectroscopic studies of exotic nuclei produced at the IGISOL have, during 2002, been performed with a particular emphasis placed on the study of nuclear isomers. The year's highlights include measurements on ground states and isomers in ytterbium (Z = 70), which were achieved at our highest ever spectroscopic efficiency, and the first optical measurements on radioactive systems in the yttrium (Z = 39) isotope chain.

Measurements on ytterbium (in collaboration with, and proposed by, G. Dracoulis, ANU) were directed at the near-stability and neutron-rich isomeric systems. New measurements were made on ^{175,175m,177,177m}Yb and, importantly, on ^{176m}Yb. The new optical Yb measurements confirm the absence of any 2 quasi-proton excitation in ^{176}Yb (unlike ^{178}Hf) with the ^{176m}Yb system observed to possess a very low, and purely 2 quasi-neutron, magnetic moment $|\mu| < 0.14$ n.m. The system was further found to be accurately described by a pure combination of the single neutron configurations that form the ^{175}Yb and ^{177}Yb ground states (also measured in the work). Importantly though the Yb isomer was shown to have only a marginally smaller charge radius than that of the ground state. This observation is quite unlike the behaviour reported by N. Boos et al for the 4qp ^{178m2}Hf isomer, where a substantial reduction in charge radius was observed. Further measurements aiming to isolate the effect of quasi-particle, particularly quasi-proton, excitation on the nuclear charge radius are underway at JYFL.

A series of measurements on yttrium isotopes were successfully performed using a multiply forbidden ionic resonance line, $s^2\ ^1S_0$ - dp $^3P_1$, at a spectroscopic efficiency two orders of magnitude lower than that possible in the ytterbium measurements. The use of the very weak line was required to ensure measurable hyperfine splittings (negligibly small in the strong $s^2\ ^1S_0$ - sp $^1P_1$ transition) and thus sensitivity to nuclear spin, magnetic moment and quadrupole moment. Only the background suppression possible with cooled and bunched beams at the IGISOL permits such measurements. Figure 3 shows a selection of resonance spectra for the ^{87,87m,88,89}Y isotopes and isomers. A 300 ms isomer, ^{88m1}Y, produced during the measurements was further used to calibrate the cooler transit time, determined to be ~ 650 ms at this mass. Further yttrium measurements, on neutron-rich species, will be made on the weak transition and all Y systems, including the very short-lived isomers, will have their charge radii investigated on the strong optical line.

Precise half-life measurement of ^{62}Ga. [7] The study of superallowed Fermi 0^+ -> 0^+ beta transitions in Z = N nuclei provides a test of the properties of the electroweak interaction. The *ft* value for a transition can be extracted experimentally from the branching ratio, the Q value and the half-life. Theoretically, a *ft* value is related to the

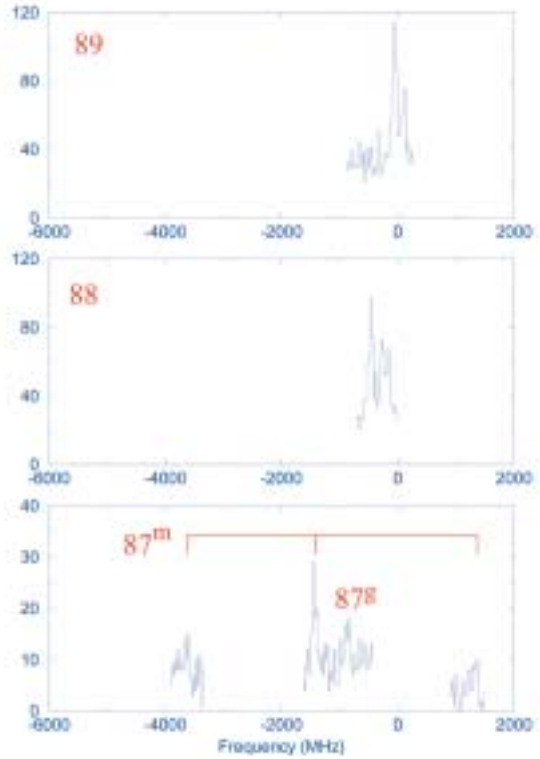

Fig. 3. Resonance spectra for the ^{87,87m,88,89}Y isotopes.

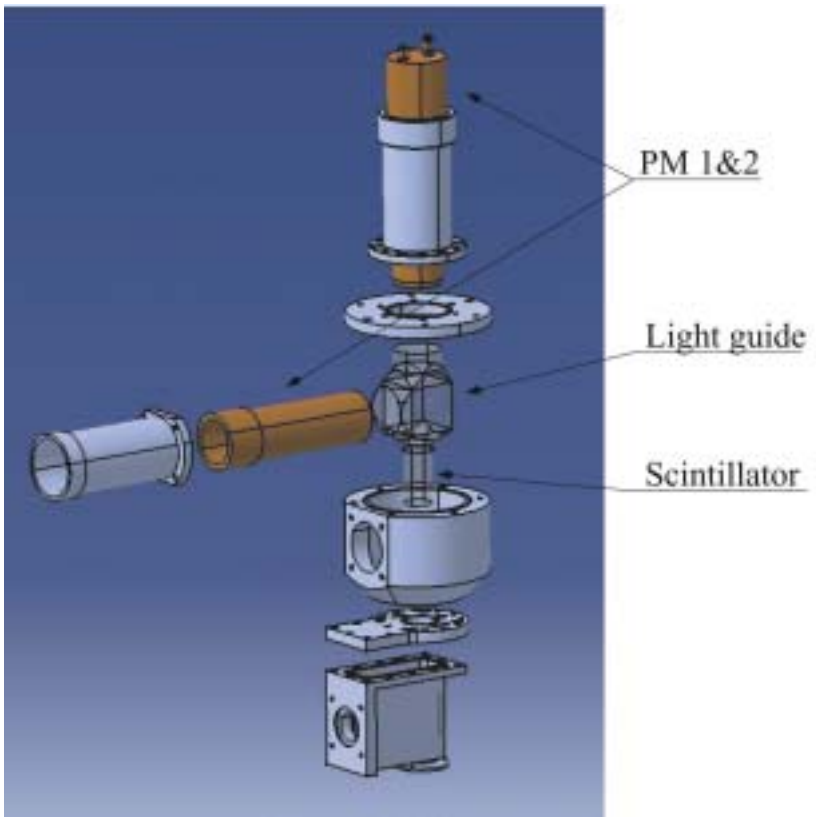

Fig. 4. A schematic view of the beta detection setup. The light coming out of the scintillator is collected on two PM

weak vector coupling constant G_V. From the *ft* values one can deduce the universal *Ft* values that take into account the radiative and Coulomb corrections. The *Ft* values do not depend on the transition and the V_{ud} matrix element of the Cabbibo-Kobayashi-Maskawa (CKM) quark mixing matrix can be deduced. The Standard Model states that this matrix should be unitary. Nevertheless, the current experimental data indicates that this condition is not fulfilled with a deviation from unitary greater than 2 standard deviations. To test the theory based radiative and Coulomb corrections, high accuracy measurements of heavier (T = 1) nuclei are required.

In 2001 an experiment devoted to determine the branching of the superallowed Fermi decay of ^{62}Ga with high precision took place at the IGISOL. This work, reported in 2001 Annual Report, was continued by a two weeks experiment devoted to the very precise measurement of the beta decay half-life of ^{62}Ga. The studied nuclei were produced via ^{64}Zn(p,3n)^{62}Ga fusion-evaporation reactions. The mass-separated A = 62 beam was implanted on a movable tape surrounded by a plastic scintillator for beta detection. Scintillation light was collected in two photomultipliers (PM) in coincidence in order to reduce the background (figure 4). The beta detection efficiency was higher than 90 %. Three high efficiency germanium detectors in a close geometry were used for gamma-ray detection.

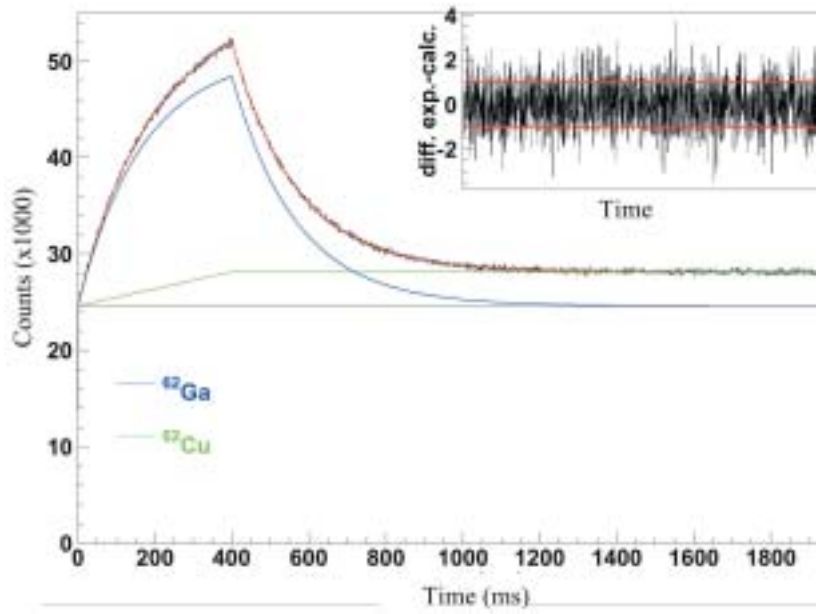

Fig 5. Fit of growth and decay periods of the collection cycles. The curve (red) is fitted by assuming two components and long-lived (constant) contamination.

Large amounts of data have been taken with various collection-counting cycles. Three different acquisition systems were used in order to confirm the fitting procedure. The analysis is in progress. Figure 5 shows a fit of the growth and decay periods of the collection cycle including beam contamination and ^{62}Ga daughter decay. With the collected statistics and quality of the data a precision better than 10^{-3} on the half-life should be reached.

Work at ISOLDE [8]

Decay studies at ISOLDE. Assuming the isospin is a good quantum number one expects symmetry between transitions from T = 1, $T_z = \pm 1$ nuclei to the common excited states in the $T_z = 0$ nucleus between them. Such an symmetry test can be performed by comparing the strengths of Gamow-Teller (GT) transitions obtained from (p,n)-type charge-exchange reactions with those obtained from the beta decay. Mass A = 58 provides an ideal case for such a comparison due to the recent high-resolution ^{58}Ni(^{3}He,t)^{58}Cu experiment in Osaka and access to laser ionised ^{58}Zn, which decays to excited states in ^{58}Cu. The beta decay of ^{58}Zn that was observed by our group for the first time at ISOLDE in 1998, was studied in 2002 with an improved experimental setup. These studies involved a high efficiency beta-gamma spectroscopy as well as dedicated search for proton decay from higher lying excited states in ^{58}Cu. The latter part of the experiment applied Si-ball array to be discussed below.

A rapid proton capture (rp) process is a part of the explosive hydrogen burning occurring in a special astrophysical events, like an accretion in a close binary systems. At high temperatures it may continue until the fuel for nuclear burning is exhausted. The typical time scale for the event, known as an X-ray burst, is 10 - 100 s. The rp-process flow proceeds quickly in the neutron-deficient side of the nuclide chart to the mass region A ~ 70, where it slows down or terminates depending on the nuclear properties. As a continuation to previous studies for ^{71,70}Kr a beta-delayed proton decay study of ^{69}Kr was performed. This decay gives an access to proton unbound states in ^{69}Br. Due to the very low production cross section for such an exotic nucleus, only few events may be expected after careful analysis.

R&D work at ISOLDE. In the target ans ion source sector, off-line release rates of Be, Mg, S, Cl, Ar, K, Ca, Sc, Mn, Ga, Br, Kr and Sn from refractory materials were studied to optimise the production of the most exotic nuclei – a key issue in research far from the stability. In addition, a complete Monte Carlo code to study and optimise ISOL-type targets was finalized. The latter task is related to the EU-funded study project EURISOL, where new generation radioactive ion beam facility to be constructed in Europe is outlined.

In connection to neutron converter target, which aims for the enhanced production of fission fragments compared to spallation products, we performed a spectroscopic study on the beta decay of neutron-rich Cs-isotopes extending to mass A = 150. We also explored decay properties of neutron-rich Fr isotopes up to mass A = 232 by impinging the primary beam directly to the UC-target, thus resulting in enhanced spallation production.

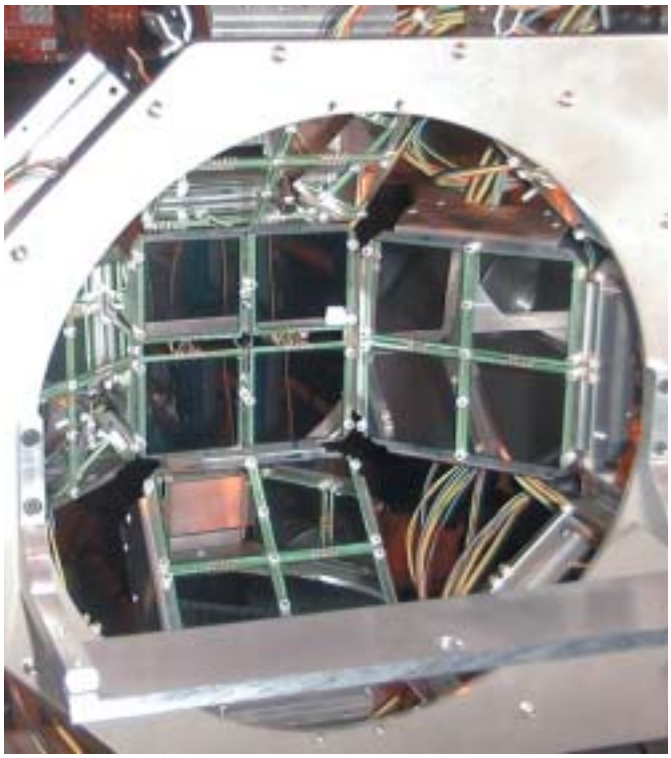

Fig. 6. A view to the Si-ball chamber with some detectors installed.

Parallel to ongoing physics program we have initiated a Si-ball R&D detector project and developed new means to produce and manipulate radioactive ions at ISOLDE. The Si-ball project aims for high-granularity charged particle detector array. The full detector consists of 104 detectors in rhombicuboctahedron geometry made of squares and triangles. The detector provides very high

geometrical efficiency close to 100%, wide energy range with very low energy threshold and high enough granularity for angular distribution measurements between emitted particles. The first half of the Si-ball was commissioned successfully in 2002 (see figure 6), and the array was applied in the beta-delayed proton decay study of ^{58}Zn mentioned above. The Si-ball is foreseen to travel to JYFL during the CERN 2003 - 2004 shutdown period.

Finally, an ion cooler and buncher development has concentrated on the simulations, which provide a basis for the technical design starting in the beginning of 2003. The operational parameters of the RFQ and the deceleration section has been optimised. Due to the very different acceptance of the RFQ and the emittance of the ion beam before the RFQ, a special matching section with an electrostatic quadrupole triplet has also been designed.

Collaborators

[1] Work carried out in collaboration with Argonne National Laboratory, Argonne, and University of Notre Dame, Notre Dame. Experiment spokesperson: A. Garcia, Notre Dame.
[2] Work carried out in collaboration with St. Petersburg Nuclear Physics Institute. Experiment spokesperson: Yu. Novikov.
[3] Work carried out in collaboration with KVI, Groningen, Osaka GAGUIN University, as well as within the Ion Catcher RTD project of the EU 5th FP.
[4] Work carried out within the Ion Catcher RTD project of the EU 5th FP.
[5] Work carried out within the EXOTRAPS RTD project of the EU 4th FP and continued within NIPNET RTD project of the EU 5th FP. Experiment spokesperson: V. Kolhinen, JYFL.
[6] Work carried out in collaboration with University of Manchester and University of Birmingham. Experiments spokespersons: P. Campbell, Manchester, and J. Billowes, Manchester.
[7] Work carried out in collaboration with CEN Bordeaux-Gradignan, IReS Strasbourg, GANIL Caen, University of Liverpool and KVI Groningen. Experiment spokesperson: B. Blank, CEN BG.
[8] The work at ISOLDE is carried out in collaboration with the Nuclear Matter Program of the Helsinki Institute of Physics.

In-beam spectroscopy

Rauno Julin

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

In-beam spectroscopy. The year 2002 was devoted to Recoil-Decay-Tagging experiments employing the SACRED electron spectrometer at RITU. In addition, a number of important test and commissioning experiments were carried out in collaboration with the RITU group. Preparations for the coming JuroGam campaign were begun.

RDT measurements with SACRED + RITU. In total, nine in-beam electron spectroscopy experiments were carried out by using the SACRED electron spectrometer in collinear geometry at the target area of RITU, most of them in collaboration with the University of Liverpool.

Earlier, a candidate line for a low-energy E0 transition in ^{194}Po was found in an in-beam conversion electron spectrum tagged with the ^{194}Po alpha decay [1]. In spring 2002, searches for similar E0 transitions from very low-lying 0^+ states of ^{192}Po [2], ^{184}Pb [3] and ^{180}Hg [4] were carried out. Further experiments for the study of these 0^+ states are needed. An interesting development will be the use of the magnetic solenoid in recoil-shadow mode at RITU, in order to attempt the detection of E0 electrons from flying recoils. This will also allow measurements of level lifetimes. Preliminary tests for such measurements were carried out in the gamma cave.

The in-beam studies of very heavy elements were continued with several electron experiments. Electron lines from low-energy yrast transitions in ^{250}Fm were detected from a bombardment of a ^{204}HgS target with a ^{48}Ca beam [5]. A first attempt to study the odd-proton nucleus ^{251}Md produced in the ^{48}Ca + ^{205}Tl reaction with a cross section of about 800nb was carried out in collaboration with the Saclay group. Two experiments were devoted to further studies of high K states in ^{254}No. The other experiment served also as a commissioning run for the GREAT spectrometer [6], designed and funded by the UK universities (see the RITU report).

M1 cascades in ^{254}No. A careful analysis of the prompt recoil-gated electron-electron coincidence spectra of ^{254}No carried out by Peter Butler and his group in Liverpool led to a highlight of the year, already published as a Physical Review Letter [7]. They found out that a broad distribution under the discrete electron lines arising from transitions within the ground state band is not due to random events but consists of high-multiplicity events, obviously originating from cascades of highly converted M1 transitions within rotational bands built on high K states in ^{254}No (Fig. 1). The bandhead of a K = 8 band is expected to lie at around 1 - 1.5 MeV in excitation energy and it is expected to have a lifetime of greater than 1 ms. Further studies of this isomer and its decay via electron cascades are needed. In these studies the GREAT spectrometer at the focal plane of RITU and the method proposed by G. Jones [8] will be employed.

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Peter Jones, senior scientist
Paul Greenlees, scientist
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Päivi Nieminen, graduate student
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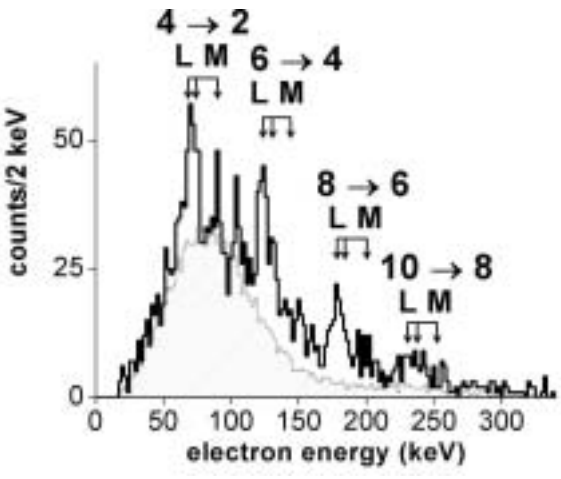

Fig. 1. A conversion electron spectrum tagged by ^{254}No recoils. The hashed area shows a simulated spectrum of electrons from M1 transitions of high K bands in ^{254}No [7]

TDR for RDT. In Recoil-Decay-Tagging (RDT) experiments prompt events from the target area and events with variable delays up to minutes from the focal plane of a recoil separator are correlated. The spectrometers at the target area and at the focal plane (SACRED or JuroGam +

GREAT) consist of many detector systems, providing a total of over 400 individual spectroscopy channels. Each channel is instrumented using its own electronics to provide time and energy signals, which should be digitised.

The sheer number of channels and delays makes conventional acquisition systems cumbersome and vulnerable to dead-time problems in the collection of the data in form of traditional event-by-event mode.

A new approach to the problem is the Total Data Readout (TDR) acquisition system [9] which collects data in a free running mode, each channel being independent. By the use of time-stamping with a resolution of 10ns, the collected data can be reconstructed to produce data in a time-ordered fashion, and be combined together to offer the physicist event-by-event data without the problematic dead-time which could be incurred under more traditional systems.

An advantage of this new approach in data acquisition is that electronic based coincidence and logic decisions, and extraction of extra information between parameters can all be performed in software to the users requirements.

The TDR system is a part of the GREAT project funded mainly by UK institutions. The first successful commissioning experiments using the new TDR system to collect events from the GREAT spectrometer and the SACRED electron spectrometer were carried out in October.

Fig 2. The TDR system housed in 3 air-conditioned racks in the RITU cave, instrumenting over 400 spectroscopy channels.

JuroGam preparations. The successful program of RDT gamma-ray experiments at RITU will continue in April 2003, with a new array of 45 Eurogam Phase I Ge-detectors from Euroball and the UK-French detector pool. The new array will have the same geometry as the original Eurogam Phase I array, with an efficiency of 4.5% at 1.3MeV.

In October the RITU cave was reconstructed (see the Fig. 3) having now a ceiling height of 4 m, high enough for the JuroGam supporting structure (from the earlier Eurogam 2) transported from Strasbourg. Testing of the Eurogam Phase I detectors, annealing and repairs have begun at JYFL and at IReS in Strasbourg. At the same time, mechanical work nears completion of the frame support, scheduled for siting around the target position at RITU in mid-February 2003. The new autofill system constructed by the University of York will then be assembled, tested and detectors mounted in the frame in early March. The TDR system will be upgraded and the JuroGam system, including the new software-suppression technique commissioned before the first experiments for the array at the start of April.

Fig. 3. Reconstruction of the RITU cave for the JuroGam campaign. Cath Scholey driving, Sakari Juutinen, Janne Pakarinen and Juha Uusitalo spectating.

References

[1] P. Rahkila et al. JYFL Annual report 2001
[2] Spokesperson P. Rahkila, JYFL; collaborators: University of Liverpool, UK
[3] Spokesperson P. Rahkila, JYFL
[4] Spokesperson A. Andreyev, University of Liverpool, UK; collaborators: JYFL, University of Leuven, Belgium
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[6] Spokesperson R.-D. Herzberg, University of Liverpool, UK, collaborators: JYFL
[7] P.A. Butler et al., Phys. Rev. Lett. 89 (2002) 202501
[8] G. Jones, Nucl. Instr. Meth. Phys. Res., A 488 (2002) 471
[9] I. H. Lazarus et al. IEEE Trans. on Nucl. Sci. Vol. 48, N:o 3, June 2001

Activity using the JYFL gas-filled recoil separator RITU

Matti Leino and Juha Uusitalo

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

The activity of the RITU group in 2002 was focused on the recoil decay tagged in-beam electron spectroscopy (SACRED campaigns) studies and RITU stand-alone studies performed at the focal plane of the separator. SACRED-campaigns are described elsewhere in this Annual Report. Stand-alone studies were carried out in the neutron-deficient translead region.

The study of ground state and intruder state systematics of neutron-deficient odd-mass At isotopes was expanded towards the odd-mass Fr isotopes. This expansion led to a first identification of an $1/2^+$ intruder state to exist in Fr isotopes, namely in ^{201}Fr. When in At isotopes the $1/2^+$ intruder represents the (4p-1h) configuration, in Fr isotopes the $1/2^+$ intruder state is built on the (6p-1h) configuration. The plan is to continue these studies in more exotic Fr isotopes [A].

Our long term plan to study the magic (N=126) uranium isotope ^{218}U was finally realized. Since there have been discussions whether the proton number Z=92 is magic or not, it is of great interest to try to study this nucleus more in detail. As it was expected the production cross-section for this nucleus turned out to be very small (well below 1 nb). Therefore only alpha spectroscopy could produce some spectroscopic information. In total 60 hours of 1.3 eμA ^{40}Ar beam on a 0.6 mg/cm^2 thick ^{182}W target yielded in total 18 recoil-alpha-alpha correlated events identified to originate from ^{218}U. Fourteen of the chains were identified to take place between the 0^+ ground-states. In addition four of the chains were identified to occur in a such way that the first α-decay (highly hindered) originates from a high-spin state and it is followed by a 0^+ ground-state decay in ^{214}Th. In the lighter even-even N = 126 nuclei it is known that a high spin isomeric 8^+ state, formed in configuration $h_{9/2}\, f_{7/2}$ and decaying by a 3 % α-branch in ^{216}Th, is coming down in energy. Therefore the identified α-decay from the high spin state can be considered to occur from an isomeric 8^+ state which has come below the 6^+ state in ^{218}U [B].

The recently installed new dipole chamber and the differential pumping system are in routine use and they have proven to increase the RITU capacity remarkably. During the year 2002 the major technical improvement work focused on the reliability of the magnet power supplies. The known existing functioning problems, when high currents were needed, were fixed by a technician visiting from the power supply deliverer Danfysik. Also the rippling of the power supplies was remarkably reduced, diminishing the possible noise affecting the performance of the sensitive detector systems used. For convenience of the users, all four magnets in RITU are now controlled by their own control panels, while before only one panel was used to tune all the magnets. Two new more powerful supplies have been ordered to be used as backup supplies for RITU, or to power the SACRED electron lens or to power the new separator system intended for future use.

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Pasi Kuusiniemi, scientist -31.8.
Catherine Scholey, scientist
Sarah Eeckhaudt, graduate student 1.10-
Heikki Kettunen, graduate student
Ari-Pekka Leppänen, graduate student

The GREAT spectrometer

The GREAT (gamma-recoil-electron-alpha-timing) spectrometer has been almost-fully installed at the focal plane of RITU and the first commissioning experiments have produced promising results. GREAT is a U.K. University and Daresbury Laboratory funded collaboration and has been several years in the making. GREAT is a unique system comprising of gas, silicon and germanium detectors in close proximity, allowing the identification of recoiling nuclei which have been transported through RITU and their subsequent decays. The spectrometer is designed to detect with high granularity and efficiency alpha, beta and proton decays as well as γ-ray transitions, internal conversion electrons and the X-rays associated to these types of radioactivity.

At the centre of the spectrometer there are two double-sided-silicon-strip detectors (DSSD), both 60mm x 40mm in total area, but 4mm apart, with a strip pitch of 1mm giving a total of 4800 pixels. Surrounding the

DSSDs on four sides are 28 PIN-diodes each with an active area of 28mm x 28mm. A PPAC which has both vertical and horizontal position sensitivity is positioned upstream to the DSSD. A segmented planar Ge detector will be placed behind the DSSDs to detect low energy γ-rays and X-rays. The crystal has an active area of 120mm x 60mm which will cover ≈ 50% of the solid angle and has strip pitch of 5mm on both faces. Behind the planar Ge detector will be a clover Ge detector for the detection of γ-rays.

The initial installation of one DSSD, the PPAC and PIN-diode box took place in July-August 2002. For the commissioning experiment a reaction of $^{208}Pb(^{48}Ca,2n)^{254}No$ at a beam energy of 219 MeV and target thickness of 630μg/cm^2 was employed. The DSSD gave an energy resolution of ≈ 8keV for conversion electrons and ≈ 20keV for alpha decays.

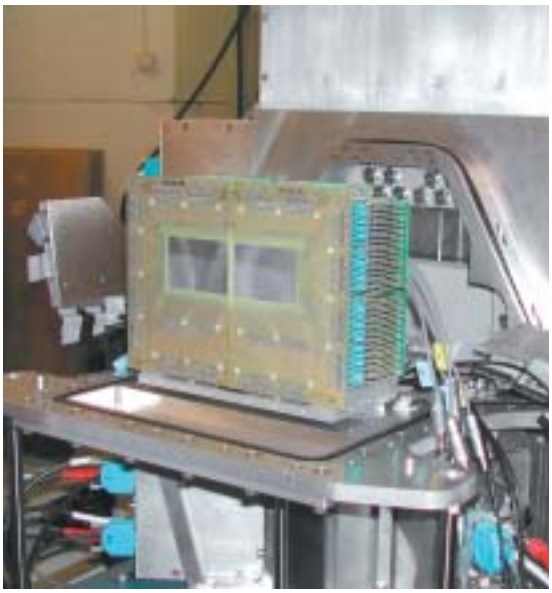

Fig 1. A picture of the GREAT spectrometer during the installation.

In November 2002 the second DSSD was installed and the GSI super clover was positioned at the rear of the spectrometer. Figure 1 shows the DSSDs, their preamps and in front the mylar foil of the gas window. Along with the detectors a new triggerless data acquisition was system was installed (see in-beam spectroscopy). Figure 2. shows an alpha decay spectrum taken from the second commissioning run. Several successful heavy element experiments have been performed using this system and we are now awaiting the arrival of the planar and clover germanium detectors.

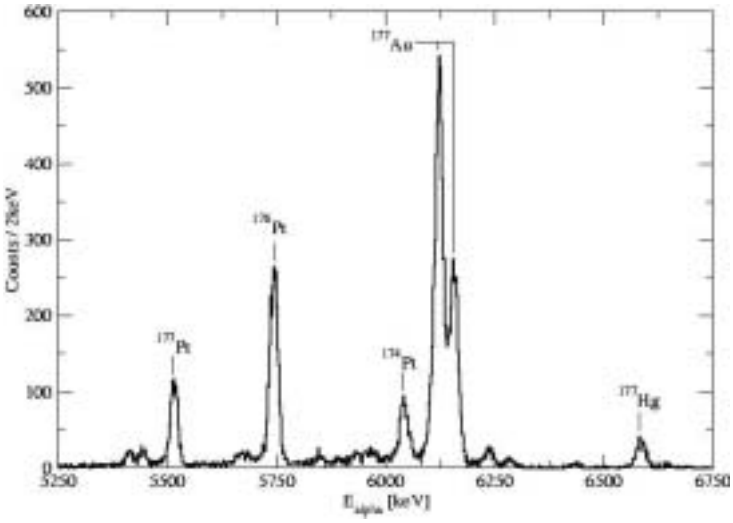

Fig 2. A calibration spectrum using a reaction of a ^{36}Ar beam bombarding a ^{144}Sm target. The ^{177}Au lines have a resolution of 18 k eV.

Spokespersons and collaboration institutes:

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Nuclear reactions

Wladyslaw Trzaska

http://www.phys.jyu.fi/research/hendes/hendes/HENDES.html
http://www.phys.jyu.fi/research/hendes/lsc/LSC.html

During the past year we were able to maintain our full research program despite some unexpected cuts in funding and despite problems with cyclotron operation and high demand on beam. In 2002 we have conducted 12 experiments. Half of them used our cyclotron and accumulated the total of over 1000 hours of beam. There were also 4 off-beam measurements, and two measurements outside Jyväskylä - at Dubna and at GSI. During 2002 17 of our publications have appeared in print and we have made about 20 conference presentations. We have strengthened our collaboration links with DEMON group and with our Italian colleagues from Legniaro and Naples. A very encouraging fact has been the steady increase in the numbers of young physics among our collaborators. All in all 51 physicists made 67 visits to our group spending about 1000 visitor days at JYFL in 2002. The longest stays were by the youngest scientists within CIMO, Erasmus and other exchange programs. Regrettably, restrictive EU policy still prohibits most of our colleagues from the benefits of travel support widely available to the others.

Wladyslaw Trzaska, senior scientist
Valery Rubchenya, senior scientist
Vladimir Lyapin, scientist (HIP/JYFL)
Jaroslaw Perkowski, Marie Curie Training Site scholar
Vladimir Maslov, CIMO scholar
Sergey Yamaletdinov, CIMO scholar
Tomasz Malkiewicz, SOKRATES exchange student

Dynamics of excited superheavy nuclei

Synthesis of superheavy nuclides remains one of the hottest topics in nuclear physics. The main experimental problem is the choice of the best reaction that would produce the compact compound superheavy system with the highest survival probability against fission - the dominating exit channel. This, in turn, depends on the interplay of the competing reaction channels, and ultimately on the dynamics of the heavy ion reactions. To contribute to the solving of these problems we have used HENDES to investigated the dynamics of excited superheavy system with Z=118 in the reaction ^{86}Kr + ^{208}Pb at EKr = 460, 500 and 600 MeV. The lowest energy is just over the fusion barrier. The mass and kinetic energy of the binary fragments have been measured by time-of-flight method. The double differential distributions of neutrons, protons and α-particles were measured in coincidence with the fragments. The neutron and α-particle probes were used for determination of the fission time scale and the relative contributions of the main gross reaction channels: deep inelastic, fast fission and decay of compact compound configuration. The light particle double differential spectra have been analyzed within the multiple-source model, which included 4 sources: two fragments, the compound nucleus, and the neck region between the heavy fragments. The evidence for the sizeable enhancement in the neck fragmentation for a highly excited, superheavy system with Z=118 has been shown.

The second superheavy system that we have studied had Z=122. It was produced in the reaction ^{64}Ni + ^{242}Pu near the Coulomb barrier. The experiment was carried out at JYFL using the double-arm, position-sensitive, microchannel-based TOF spectrometer CORSET. CORSET was used for fission fragment registration while double differential distributions of neutrons in the coincidence with fragments were measured by the TOF method with 8 DEMON detectors and 3 position sensitive neutron detectors (HENDES modules). In addition, γ-ray multiplicity has been measured with an array of six 6363 mm NaI(Tl) detectors, installed in the lower hemisphere at 25 cm from the target. In the experiment, mass and energy distributions of fission fragments, fission, quasi-fission and evaporation residues cross-sections, multiplicities of neutrons and γ-quanta and their dependence on the mechanism of formation and decay of compound systems have been studied.

Comprehensive study of ternary fission

We have successfully completed a large multiparameter experiment on ternary fission of ^{252}Cf using the CODIS2 detector system and two GSI segmented Super Clover γ-ray detectors. The man goals of the experiment were: gamma-ray spectroscopy of fission fragments, angular anisotropy of γ-rays in binary and ternary fission with special attention paid to the comparison between the

binary and ternary data, emission of LCP in excited states (including the ^{10}Be puzzle) and LCP yields.

Cluster states in light and medium-light nuclei

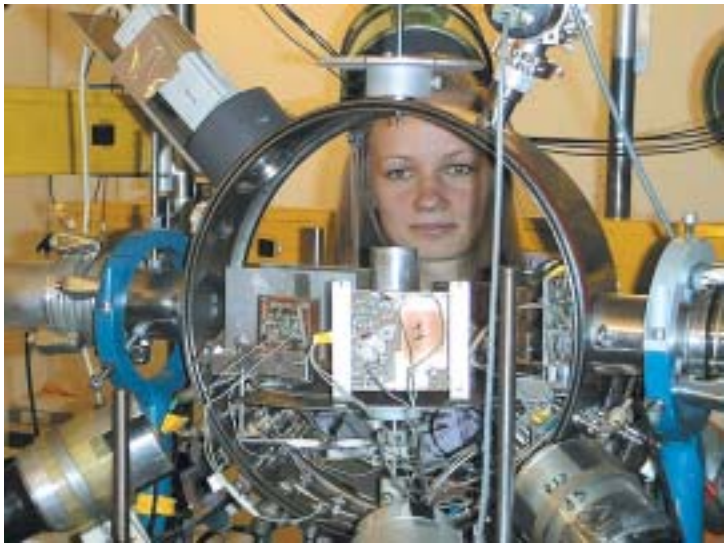
Investigation of nuclear matter under extreme conditions makes the most demanding test of nuclear structure models. In the experiment carried our using radioactive ^{8}He beam at Dubna we have investigated the T=5/2 states in ^{9}Li (isobaric analogs of ^{9}He). The experiment was performed at energies 55 and 62 MeV with the intensity of the secondary ^{8}He beam of about 1000 pps. The primary beam of 30 MeV/u 11B was fragmented on a thick ^{9}Be target and the fragmentation products were analyzed with ACCULINNA separator. The ^{8}He beam was than slowed down by a thick Be wedge. Two thin plastic detectors in the flight path upstream of the experimental area provided event-by-event identification of the incoming particles. The scattering of 8He on p was performed in a 50 cm scattering chamber filled with methane gas serving as a proton target. The gas pressure was adjusted to stop ^{8}He beam just before the telescope of dE-E detectors positioned at zero degree with respect to the beam. The gas volume was separated from the ion guide by a thin organic foil. Before the entrance of the scattering chamber a 60-micron Si detector was used. After the entrance a short (80 mm) windowless ionization chamber was placed. These detectors served as the final identification of the ^{8}He ions and to discriminate against reactions occurring in the Si detector, in the window foil, etc. Five telescopes of dE-E Si detectors, one at zero degree and four on the sides of the central telescope were used to identify the products of the reactions of ^{8}He with the target gas.

In our studies of a-clusterization in medium-light nuclei (20 A 40) we have m oved towards heavier species and higher excitation energies. While the previous experiments looked at ^{16,18}O+α and ^{20,22}Ne+α (both measured at JYFL) or ^{18}Ne+α (measured at CRC in Louvain-la Neuve) we have now investigated ^{28,30}Si+α and ^{36}Ar+α with ^{40}Ar+α serving as a reference. The new measurements were made possible by the acquisition by the collaboration (Åbo Akademi and INFN Catania) of several 5 mm thick silicon detectors. By going to higher beam energies we could cover a larger span of excitation energies (up to about 30 MeV) and take a better advantage of our thick target method. The data analysis, still in progress, is very demanding and tedious but should yield a valuable insight into the development and systematics of α-cluster states in medium-light nuclei.

Nuclear rainbow and cluster decay

Our work on nuclear rainbow phenomenon in the light heavy ion collisions produced new data on ^{16}O+^{14}C elastic scattering at 281 MeV. The results were compared with the other three systems: ^{16}O+^{12}C, ^{16}O+^{16}O, ^{12}C+^{12}C, which were thoroughly studied previously, also at JYFL. Refractive type of scattering dominates in all the systems. It is clearly contrary to the expectations for the ^{16}O+^{14}C system. The ^{16}O+^{12}C and ^{12}C+^{12}C scattering demonstrate a new phenomenon called “abnormal nuclear dispersion” that is absent from ^{16}O+^{16}O. The theoretical analysis is still in progress, although important information on the applicability of the folding model of nucleus-nucleus interaction, influence of polarization potential and energy dependence of the mean nuclear field has already been obtained. In December the data on large angle ^{16}O+^{12}C scattering has been further improved to remove the remaining ambiguities in interpretation. We can already say that the agreement of our new optical model calculations with the data is remarkable.

The excitation function of the fusion-fission reaction ^{22}Ne+^{208}Pb was measured at seven energies (90-130 MeV) covering the deep sub-barrier region. Solid state track detectors located in a specially constructed scattering chamber were used. For the first time the direct comparison of the three processes: cluster decay, elastic scattering (measured previously at JYFL) and fusion, corresponding to the same participants (^{23}0U, ^{22}Ne+^{208}Pb) became possible. We expect to provide important information on the internal part of the interaction barrier and, correspondingly, on the mechanism both of cluster radioactivity and near-barrier reactions.

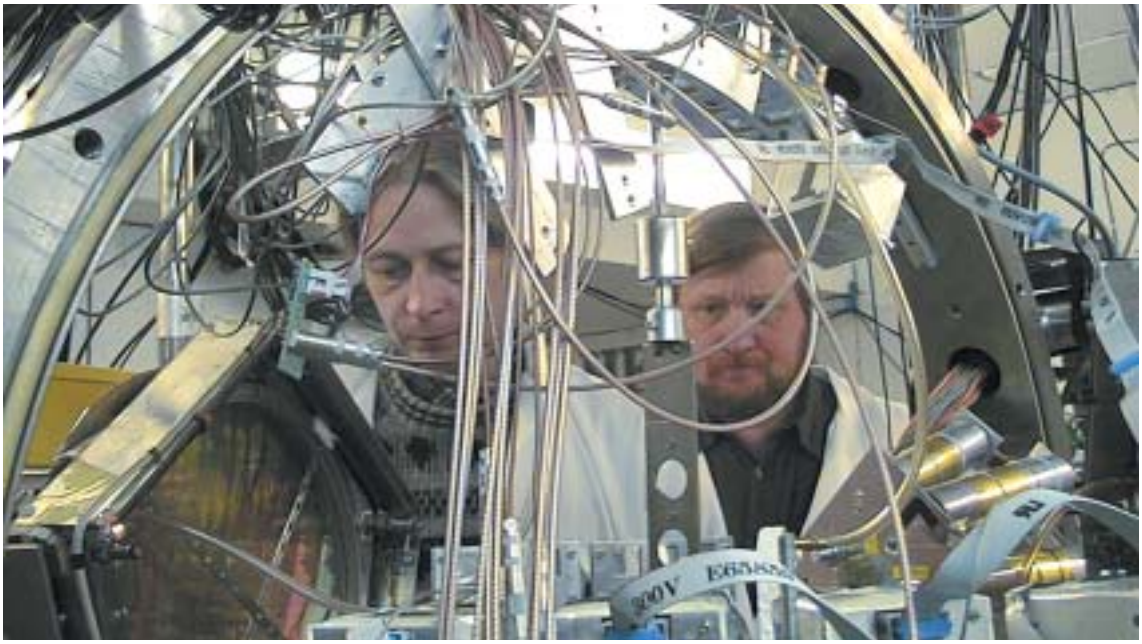


New analysis techniques

Our interest in the fine structures in the mass-energy distribution of fission fragments and the search for new, exotic modes of fission such as collinear cluster tripartition has lead us to the development of new detection and calibration techniques. For instance, In order to measure the mass of the fragment originated from many-body decay TOF-E (time-of-flight - Energy) method must be used. High-aperture detector modules like the ones we use make it possible if the problem of the relatively thick entrance windows of the module is solved. A typical energy loss of the light fragment can reach as much as 60% of the initial energy. Naturally it causes significant errors in the reconstructed value of the fragment energy ("energy at emission") and, consequently, in the fragment mass. The problem is further complicated by the know deficiencies in the tabulated values of energy losses of the low-energy heavy ions. To solve the problem we have tested different procedures of mass reconstruction. The best approach we could find estimates the thickness of the start-detector foils (and of the radioactive source backing) together with the constant parameter of time calibration by fitting calculated TOF-TOF mass (m_{tt}) spectrum to the known one. A similar procedure is used for the estimation of the thickness of the stop detector windows. Calculated and known TOF-E mass spectra are compared in this case. Then for the fragments with a distinct mtt value we obtained the mean amplitude <A> of the signal in the ionization chamber and the corresponding calculated energy E_{ch}. The dependence E_{ch} versus <A> is used as a calibration curve.

Energy loss measurements

High quality data on the energy loss of charged particles, especially heavy ions, in thin foils remains scarce despite many years of research. Good results achieved with our new setup consisting of an MCP-based TOF spectrometer combined with a silicon detector motivated us to continue this line of research. In particular we have made direct comparison of TOF - E and TOF - TOF methods to solve the discrepancy in the low-energy data. We have also started measurements of energy loss of fission fragments as this data is of crucial importance to our fusion-fission research.



Ion beam based materials physics and applications

Jyrki Räisänen and Ari Virtanen

In the year 2002, the group of Ion Beam Based Materials Physics and Applications has continued previously lunched projects.

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Petri Nokisalmi, MSc student
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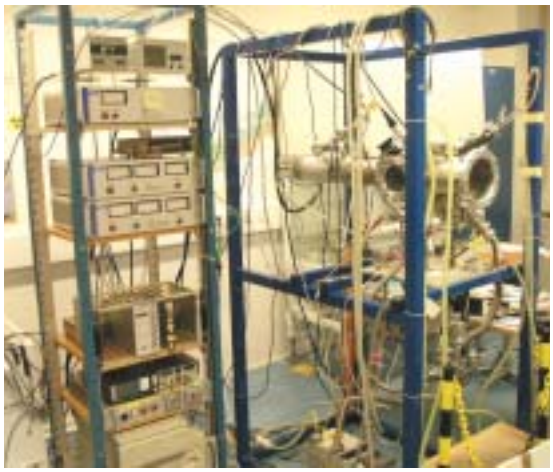
http://www.phys.jyu.fi/research/applications/index.html

Diffusion studies by radiotracers.

A big step forward in our radiotracer based materials research during the year 2002 was that we obtained at our disposal several experimental set-ups from the University of Stuttgart and Max-Planck-Insitut für Metallforschung. These devices form one of the cornerstones of diffusion studies employing radioactive beams. The set-ups consist of two sophisticated sputtering stations for performing sample serial sectioning by low energy ion beam sputtering. Also an annealing station equipped with the capability of performing annealing under ambient gas flow or vacuum was included.

An extensive study of As diffusion in SiGe alloys was initiated and experiments were completed during 2002. The full range of $Si_{1-x}Ge_x$ materials from x=0 to x=1 has been covered. In this project radioactive ^{72}As and ^{73}As beams at Jyväskylä/IGISOL and CERN/ISOLDE have been used for sample implantation.

The self-diffusion of Si in $MoSi_2$ was studied in collaboration with the University of Stuttgart, Max-Planck-Insitut für Metallforschung, University of Münster and the IGISOL group. The radioactive ^{31}Si beam produced by the IGISOL facility was employed and the experiments proved to be very successful.



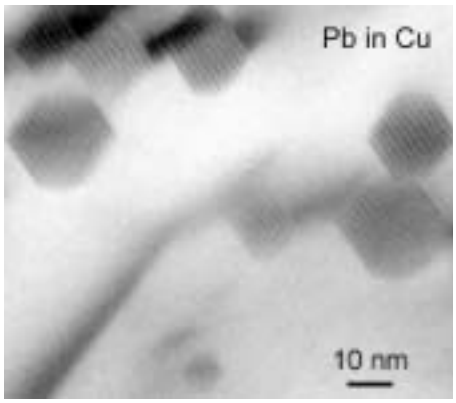
Stationary and mobile sputter stations

Far-from-equilibrium ion beam modification of materials and fabrication.

Lattice Location of Er Implanted into $Si_{1-x}Ge_x$ Alloys. There is an urgent requirement for an optical emitter that is compatible with standard, Si-based ultra-large-scale integration technology. Er incorporated into semiconductors shows characteristic luminescence around 1.54 mm that turned out to correspond to the minimum absorption in silica based fibres widely used in optoelectronics and telecommunication. Although optical prop-

erties of various Er/semiconductor systems have been given with a big deal of attention for the last decade, structural and thermal properties of such systems are very poorly studied. Among a variety of semiconductor hosts, $Si_{1-x}Ge_x$ alloys form a promising material for fabrication of next generation optoelectronic devices because of high integrability with conventional silicon technology. Adding just a few percent of Ge allows to manipulate with electronic properties of material and, thereby, to change also optical emission from incorporated Er atoms. Optical activity of Er is known to depend strongly on the lattice location of the impurity in the host matrix. In this project we have studied lattice location of Er in $Si_{1-x}Ge_x$ alloys with different composition x. By using ion implantation as a non-equilibrium technique, concentrations of Er in solid solution with the components of the alloys can be extended well beyond the thermodynamical equilibrium solubility limit. High crystalline quality $Si_{1-x}Ge_x$ alloys with x = 0.25 and 0.80 grown by chemical vapour deposition were implanted with 70 keV Er^+ ions to a fluence of 10^{15} cm^{-2} at temperature of 550°C. The implantation was found to result in Er depth distribution with 1 at.% maximum concentration that is much higher than equilibrium solid solubility limit attainable by other methods like, e.g., doping during growth by MBE. Lattice location of erbium atoms in the host matrix has been derived through rigorous computer simulation of experimental axial channelling angular scans measured by in-situ Rutherford backscattering (RBS)/channelling spectrometry. Using computer code FLUX 7.7 it has been shown that lattice location of Er atoms strongly depends on stoichiometry of the host matrix. Summary of various types of Er occupancies found in $Si_{1-x}Ge_x$ is presented in the table. Although Er tetrahedral interstitial sites were predicted theoretically and observed experimentally in crystalline Si, in our experiments it has been shown that Er can occupy different kind of lattice sites in $Si_{1-x}Ge_x$ matrix and, therefore, the optical properties are expected to vary with the alloy composition. The project has been carried out in a collaboration with Ørsted Laboratory, the Niels Bohr Institute, Denmark.

Lattice site	$Si_{0.75}Ge_{0.25}$	$Si_{0.20}Ge_{0.80}$
Ytterbium	60%	30%
Tetrahedral	10%	5%
Hexagonal	-	20%
Substitutional	-	40%
Random	30%	5%

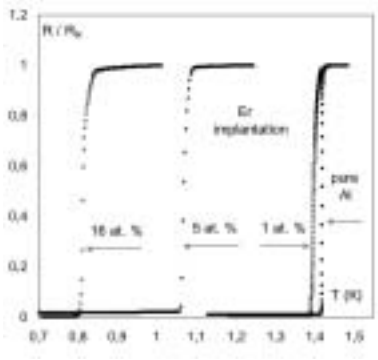


Embedded Nanostructures Formed by High-Fluence Ion Implantation Metallurgy.

Processing of metastable alloys by ion implantation has shown that when the equilibrium terminal solubility limit is exceeded, solid nanoscale precipitates can be formed from the alloying material in the matrix. The precipitates can be considered as embedded nanoscale laboratories (1 to 100 nm in size) where non-trivial size-dependent properties of condensed matter at nanoscale level can be studied. In many cases ion implantation is the only way to produce nanoprecipitates with size of 1-10 nm. The terminal solubility of Pb in Cu is extremely low and does not exceed 0.09 at.% at 875 K. High-fluence ion implantation of Pb ions at 100 keV into Cu single crystals produces metastable solutions. Annealing of the samples causes redistribution of the implanted atoms to equilibrium or near-equilibrium aggregate states which may be reflected in a change in the type of impurity lattice location in the host matrix. We have studied the effect of annealing on single crystalline Cu implanted at temperatures around 375 K with Pb to a concentration of 1-2 at%. Rutherford backscattering/channelling analysis and transmission electron microscopy (TEM) of the as-implanted samples have shown that the implanted Pb forms a supersaturated solid solution with a major fraction of the Pb atoms located on substitutional sites in the host matrix or in very small clusters. At higher temperatures the Pb-Cu solid solution was observed to become unstable and decomposed by outdiffusion of substantial Pb fraction to the surface whereas the rest Pb was found to agglomerate into nanoscale precipitates (shown in the figure). RBS/channelling and TEM analysis revealed that the Pb precipitates were crystallined at room temperature and aligned in parallel cube orientation relationship with the Cu matrix. Melting and solidification of the precipitates have been followed by in-situ channelling measurements. Melting was found to be size-dependent and was associated with a large superheating effect. Solidification of the precipitates was observed at temperatures above the bulk melting point of Pb and may be taken as an indication for a pressure broadened phase transition. Our major collaborator in

this project is Ørsted Laboratory, the Niels Bohr Institute, Denmark.

Ion Implantation for Microdevices Fabrication.
Fabrication of metal-I – insulator – metal-II tunnel microstructures requires creation of a thin insulating barrier between the two electrodes. Aluminum is typically used as one of the materials due to the well-known process of the surface oxidation forming an insulating layer of desired parameters. However, aluminium is a superconductor below 1.2 K. For some ultra-low temperature applications, superconductivity is not of an advantage. Developing of a method how to suppress aluminium superconductivity without significant degradation of the metal is very challenging. In this application various magnetic atoms were implanted into Al films. It appeared that the critical temperature of the superconducting transition of aluminium films gradually decreases with increasing of the implantation dose. The figure shows typical resistive transitions of a 100nm thick Al film before and after implantation of Er with various atomic concentrations. Extrapolation of this method to suppress superconductivity of pre-fabricated tunnel microstructures metal - aluminum oxide – aluminium is very promising for micro- and nano-devices fabrication. The project is carried out in collaboration with group of Nanotechnology and Physics of Nanostructures at JYFL.



Developing of novel ion beam based analytical techniques for materials science.

Slow Highly Charged Ion based Time-of-Flight Secondary Ion Mass Spectrometry with Angular and Energy Resolution Option (SHCI-ToF-SIMS-AERO)
TOF-SIMS is one of the most advanced surface analysis techniques in materials science with a record sensitivity to all elements from H. This analytical technique involves primary ion beams of typically 0.5-30 keV energy impinging upon a sample surface and then extracting and analyzing the generated secondary ions. Two types of SIMS are currently in use, dynamic and static. Dynamic SIMS is a destructive technique where primary ion current is high and the sample is quickly eroded so that elemental concentration of the bulk material can be measured. All the information about surface itself is lost. In static mode primary ion dose is of the order of 10^{12} cm^{-2} that corresponds to only ~0.001 of a monolayer, so that static SIMS can be considered as practically non-destructive. The great advantage of the static mode is its extreme surface elemental sensitivity in the parts per million range, i.e. ~10^{9} cm^{-2}. Conventional static SIMS that is commercially available always employs singly charged ions and is in general not a quantitative technique. The reason is the unknown secondary ion production probability as a function of the chemical environment at the surface. It is believed that the intense perturbation of the surface electronic system by primary slow highly charged ions (SHCI) enhances the ionization probability of the secondary ions leaving the surface. A strong decoupling of the ion production probability from the elemental ionization potential afforded by highly charged ions is expected to enable a more quantitative analysis of surface layers by static SIMS. Realization of TOF-SIMS will allow us to use the advantages of ECRIS 6.4 GHz and make it possible to combine non-equilibrium materials modification by SHCI with *in-situ* high sensitivity analysis. SCHI-ToF-SIMS-AERO spectrometer with high energy and angular resolution has been fabricated at JYFL and its installation is ongoing project.

Stopping Powers of Energetic Heavy Ions in Solids.
A study related to stopping powers of heavy ions for Si_3N_4 and mylar polymer have been carried out in collaboration with the Department of Applied Physics, Universidad Autónoma de Madrid and the Nuclear Reactions Group at JYFL.

RADEF facility

Several test campaigns were performed at RADEF during the year 2002. Over 20 people from seven countries representing institutes and companies like ESA, CNES, HIREX, ONERA, CERN, Patria, HIP and universities of Århus and Warsaw were involved in the tests.

The advanced semiconductor devices are assembled the way where the complete failure assessment requires high penetration ions. With the help of our new 14 GHz ECR ion source the maximum penetration depths in silicon

Researchers from HIP, CERN, University of Warsaw and JYFL gathered for the break.

can range from 100 up to even 200 microns for heavy and light ions, respectively.

This was also the interest of ESA in its evaluation of RADEF's capability to perform irradiation tests with high penetration ion cocktails. Also, the national technology agency of Finland, Tekes, allocated money for the development work of RADEF. As a consequence of these, an invitation to approve a five years contract with JYFL under ESA's technology research TRP-programme has recently been expressed in agency's industrial policy committee. The plan is to start the contract with a one-year upgrade and development phase. This would also give to JYFL an official external laboratory status of ESA.

Francoise Bezerra (CNES) and Juha Kuitunen (Patria) happy with the results.

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Major foreign collaborators for applications:

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- N. Bassler, University of Århus, Denmark
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Nuclear Structure, nuclear decays, rare and exotic processes

Jouni Suhonen

Nuclear structure of solar-neutrino detectors

The rather long-standing 'solar-neutrino problem', the strong discrepancy between the measured and the solar-model predicted neutrino flux on the Earth, has been solved by the resent Super-Kamiokande and SNO experiments verifying neutrino oscillations as source of this discrepancy. The neutrino-oscillation measurements give indications e.g. about the neutrino-mass hierarchy. This hierarchy is still not completely known and present and presently planned solar-neutrino experiments hope to shed light to this problem. For the involved detector nuclei there is usually some experimental information available to determine the strength of the relevant neutrino-induced transitions between the parent nucleus and the daughter. However, this data is not always enough and, consequently, theoretical predictions are needed to complete the neutrino-nucleus cross-section analysis. To this aim, 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.

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 ß$^-$-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 comparison with theory is expected to be possible in 2003.

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Neutralino-nucleus elastic scattering

The study of the cold dark matter of the Universe is one of the key issues of the present-day astrophysics, astroparticle physics, neutrino-physics, neutrino-cosmology, etc. because discovering the nature of the dark matter helps in understanding the past, present and future evolution of the Universe in a much more accurate way. Recent particle-physics theories seem to favour light supersymmetric particles (LSP), like the neutralino, as constituents of this matter. 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 started the neutralino-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. To access the quality of the calculated ground-state wave functions we have also calculated the ground-state dipole moments for the above nuclei and compared them with the data.

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

Systematic study of alpha decays to 2^+ states

The alpha-decay fine structure in decays to excited states of the final nucleus is a difficult object for a theoretical study. Some preliminary attempts have been made to theoretically account for the huge variation of the alpha-decay hindrance factors from one nucleus to the other. A lot of experimental effort is being invested presently to measure more and more accurately a wider selection of nuclei to produce systematics of the values of the hindrance factors. Extensive theoretical calculations are called for to study the variations of the hindrance factors and to explain them from a microscopic nuclear-structure point of view. We have started 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 with 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.

Microscopic description of two-phonon states

Microscopic description of low-lying two-phonon states in even-even nuclei has been developed. The main bilding 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 transition matrix elements are derived in terms of the metric matrix. The model has been applied to the ^{106}Pd and ^{108}Pd nuclei, known to contain two-phonon structures. In spite of its simplicity, the model predicts energies and ratios of B(E2) values in a reasonable agreement with the data. Calculation of the electromagnetic properties of the two-phonon states in the $^{116\text{-}130}$Cd chain of isotopes, partly related to the experimental work of the IGISOL group, is in progress.

Double beta decays to excited 0^+ states

We have recently 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. In the calculations it was found that the two-phonon-type of 0^+ states are only very weakly populated by this decay, thus escaping detection, but that a massive source made of ^{96}Zr could yield to majorana-neutrino masses below 0.1 eV when presently planned underground installations could be used for tracking measurements combined with gamma-coincidence methods. This unofficial proposal for an experiment has been coined “ZORRO” (Zirconium ORiented Rare-events Observatory) by our group. Further analyses of the 0^+ decays have been performed recently for almost all the possible double-beta-minus and double-beta-plus decaying nuclei.

Materials physics

Physics of nanostructures and nanotechnology

Ilari Maasilta and Jukka Pekola

The nanophysics research at Jyväskylä has several main directions. Common to all of them are the fabrication and measurement facilities, which include a modern electron-beam lithography facility, several evaporators and many dilution refrigerators operating down to 40 mK, among others. Active development and optimization of fabrication and measurement processes continues in scanning-probe-based lithography, new resists technologies, and design and development of refrigerators.

Thermal properties of nanostructures

One of the main research directions is thermal effects and transport in nanostructures. This subfield has both a basic and an applied component. The basic research concentrates in understanding how nano- and micro-scale electronic systems dissipate their heat into the solid substrates and how this heat is transported away from low-dimensional support structures. In terms of excitations, we can speak about the electron-phonon coupling and phonon thermal conductance. The applied part of the research tries to put this understanding into use in detector development. Thermal transport considerations are a limiting factor in many types of ultrasensitive radiation detectors that are actively studied in Jyväskylä. Novel FIR and mm-wave bolometer and X-ray calorimeter development is in progress and is supported by the ESA, this research aims to develop the detector technologies for the ESA XEUS mission.

Electron-phonon interaction in disordered mesoscopic conductors

We have used symmetric normal metal-insulator-superconductor (NIS) tunnel junction pairs, known as SINIS structures, for ultrasensitive thermometry in the temperature range 50 - 700 mK. With the help of these thermometers, we have developed an ac-technique to measure the electron-phonon (e-p) scattering rate directly, without any other material or geometry dependent parameters, based on overheating of the electron gas. This rate can be measured as a function of any adjustable external variable, such as bath temperature or heating power, yielding more information than the standard DC heating experiment. In addition, by measuring both the electron and the lattice temperature simultaneously, we show that the phonon gas is typically overheated as well. By taking the phonon temperature into account in the analysis, we have for the first time shown that the e-p scattering rate in a well studied and common disordered thin-film material Cu follows a T^4 temperature dependence, indicative of impurity and boundary mediated e-p coupling, instead of the commonly used and assumed T^3 law for the clean (ordered) case.

This result has several practical consequences: Compared to a lower power dependence, it is harder to cool the

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

electrons with cold phonons, i.e.the electron gas decouples from the lattice more strongly at the lowest temperatures. Direct electron cooling, also extensively studied in Jyväskylä, becomes then more important. On the other hand, this means that a sensor based on hot electron effects is even more sensitive, since the ultimate noise equivalent power of such a detector is proportional to the square root of the electron-phonon thermal conductance.

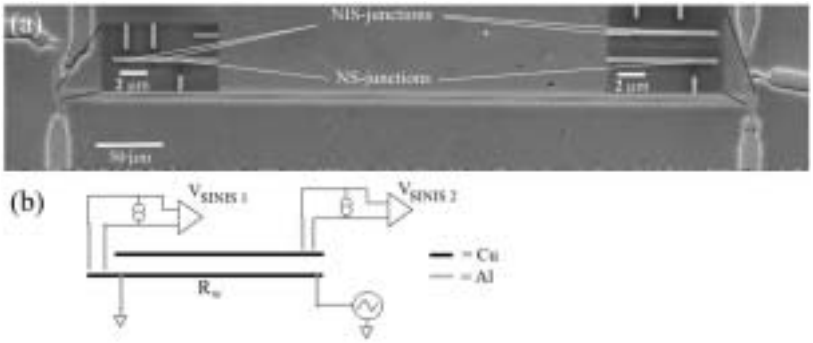


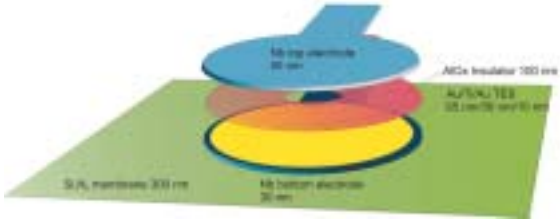
Fig 1. (a) An SEM image of a sample used to measure electron-phonon coupling. The horizontal lines are the Cu wires, the vertical lines are Al leads that form the junctions at the intersections with the Cu line. The insets are enlargements of the areas, where the junctions are located. Note that aluminum lines appear as black shadowy lines. (lighter vertical lines are Cu shadows on top of the Al lines) (b) The schematic of the sample and the measurement circuit.

X-ray microcalorimeter development

We are currently involved in two projects funded by the European Space Agency (ESA), which aim at developing a state-of-the art cryogenic imaging spectrometer for ESA's ambitious X-ray Evolving Universe Spectroscopy (XEUS) –mission. The current plan for the imaging spectrometer consists of a 32 by 32 array of transition-edge sensor (TES) microcalorimeters operated at 100 mK. The planned energy range is 100 eV – 30 keV with expected resolution of 2 eV (FWHM) at 1 keV energy and 5 eV at 7 keV.

The first project is a collaboration of many European institutes, led by the Space Research Organization of Netherlands (SRON) and focuses on developing all aspects of the imaging array. These include for example a multiplexed SQUID readout and developing fabrication techniques for array support structures and mushroom – shaped absorbers to achieve a filling factor of at least 95 %. Our task is to measure the thermal characteristics of the micromachined structures and detector materials at low temperatures.

Another project, started at the end of 2002, focuses on understanding the physics of a single pixel and thus finding ways of optimizing the performance. Presently, the standard design is a square device. Even though impressive results have been achieved, 4.5 eV at 6 keV being the record, theory predicts even better performance. All groups working in this field have reported of excess noise in the square TESs, whose origin was unknown. To study this phenomenon we developed a circular device based on the Corbino disk geometry. The advantage of this design is that the evolution of the superconducting phase at the operating point can be analytically modelled. We have found that the excess noise arises from random fluctuations of superconductivity in regions close to the critical temperature. The relative effect of this noise increases when approaching a fully superconducting state.



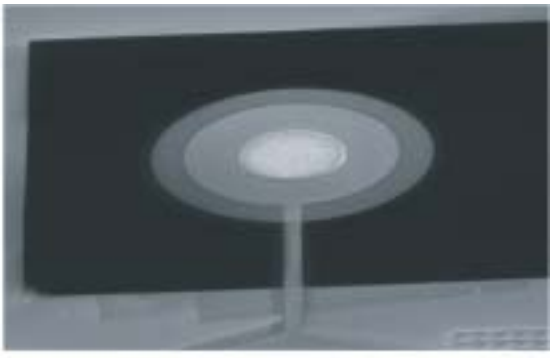


Fig 2. (top) A schematic view of the structure of a CORTES (Corbino disk TES). (bottom) Electron microscope image of an actual device with a 2 mm thick Cu/Bi absorber in the middle.

Superconducting nanostructures

In addition, electronic properties of superconducting nanostructures are also a major part of our activities. Jyväskylä is a member in an EU consortium, whose goal is to develop quantum gates (bits) based on the superconducting Josephson junction technology. We have succeeded in fabricating single electron transistors out of Niobium using traditional lift-off techniques, and fur-

ther work on the feasibility of Nb as the quantum bit material is in progress. Also, interferometric applications of superconducting loops are studied.

The field of quantum information has had a very fast development over the last years. From the many systems proposed as qubits, solid-state implementations and in particular the superconducting bits form a special class, due to their scalability, on-chip easy integration of write/ read-out components, fast operation, and relatively long coherence time scales. In Jyväskylä we are studying experimentally and theoretically the "charge" version of a squbit, in which the two quantum states of the qubit correspond to the presence or absence of a single Cooper pair on the island.

Fabrication and measurement of Nb-based SET's

In continuation of our work on mesoscopic superconducting Nb wires, we have fabricated and studied single-electron transistors with Nb-(AlOx)-Nb and Al-(AlOx)-Nb junctions. Fabrication of these devices by conventional e-beam lithography is believed to be hampered by outgassing from the resist during Nb evaporation, so other groups have resorted to more complicated multilayer techniques to produce them. In our case however the special geometry of the UHV chamber allows a reliable fabrication of Nb junctions using conventional recipes. The samples measured so far have shown a suppression of the Nb island gap to about 66% of the bulk value (1.5 meV). We believe this is due to the formation of an Al-Nb alloy in the junction, which does not get fully oxidized. The switching current as a function of the gate voltage shows a 1e modulation, although the temperature we are working at is about one order of magnitude lower than the estimated 1e – 2e crossover temperature. We have also discovered an intriguing series of 2-3 resonant peaks in the subgap IV characteristics.

A detailed study of mixed of Nb and Al SSET's (Al-Nb-Al and Nb-Al-Nb) has been started, with focus on the subgap features. The structure with a Nb-island is expected to be better for quantum computation since the difference in the Nb and Al gaps will make the lifetime of unwanted quasiparticles on the island smaller. The IV characteristics of these structures are very rich (see Fig. 3). The low-bias voltage IV characteristics of a SSET with Nb island and Al leads presents indeed a series of equally spaced peaks, corresponding to resonant transitions between quantum states determined by the charge of the island and the charge transferred through the circuit. We also find that these resonances vanish at the same time as superconductivity is suppressed in Al, thus confirming that they are related to the tunnelling of Cooper pairs only. The gate modulation at the bias voltage corresponding to the peaks was 1e for the samples we have analysed; however, the amplitude of the modulation was larger than that of the supercurrent. This suggests that biasing the SSET at a resonant peak might be better for quantum computation purposes.

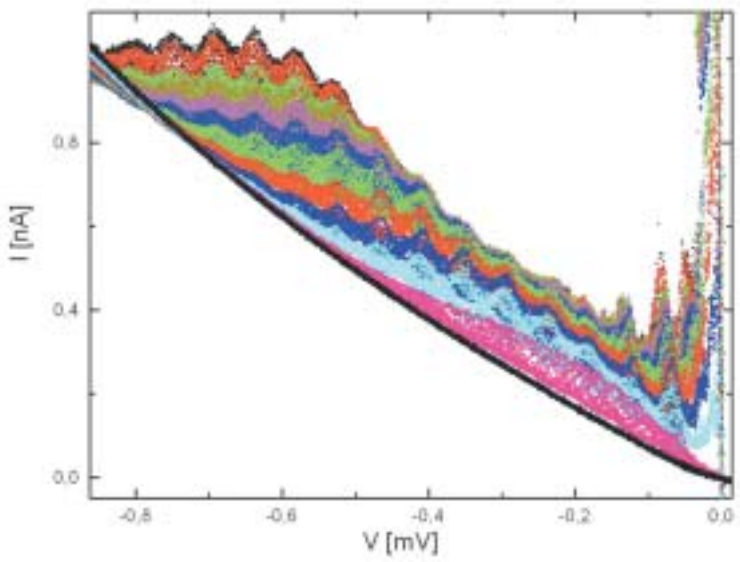


Fig 3. Low-bias voltage IV characteristics of a SSET with Nb island and Al leads in magnetic field. The lowest curve (black) corresponds to a total suppression of superconductivity, while the uppermost one is in zero magnetic field. The positions of the peaks change with the gate voltage, in agreement with the theory of resonant Cooper pair tunnelling. In the figure the IV's for a certain magnetic field at various gate voltages are represented with the same colour.

Multi-junction multibit circuits: the 3-junction Cooper pair pump

The Cooper pair pump: As a new step in our work on the Cooper pair pump we have recently concentrated in improving the filtering of the cryostat. They now include p-filters at 4.2 K and several continuous RC-filters ("strip-filters") working at 1.5 K and at the temperature of the sample stage. Also the sample geometry has been optimised to filter out non-equilibrium quasiparticles. As a result, the signal-to-noise ratio has increased, but the quasiparticles still seem to play an important role in the IV characteristics of the device. However, an encouraging feature is that the tunnelling is in fact 2e-periodic: the quasiparticles only introduce 1e random fluctuations on the islands and thus effectively an offset of the gate charge, as shown in the contour plot of fig 4. Thus, the

honeycomb structure is shifted by a period of 1e in four different places, which correspond to the four different configurations of extra quasiparticles on the islands. Because the measuring time is longer than the characteristic fluctuation times of these quasiparticles, we see all four structures superimposed.

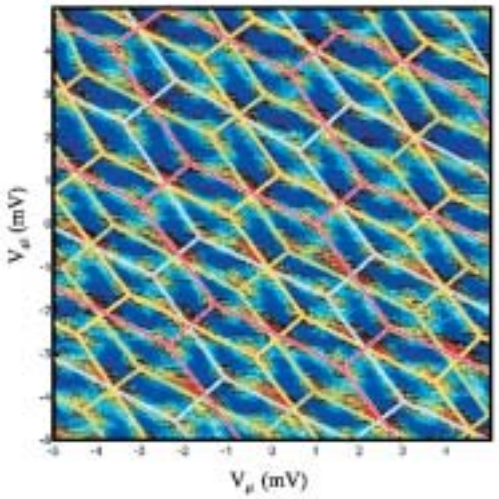


Fig 4. Contour plot of the supercurrent in Cooper pair pump measured as a function of the two gate voltages V_1 and V_2. The lines correspond to the degeneracy of the ground state of the charging Hamiltonian and thus to the maximums of the supercurrent. Four different 2e-periodic structures are plotted with different colours. As seen from the figure they are clearly e-shifted compared to each other.

Superconducting interferometry and nanowires

New type of quantum solid state interferometer is proposed. The effect is observed in hybrid non-singly-connected metallic nanostructures at temperatures below 1K. These systems might form a basis for a new generation of quantum logic devices. We have fabricated a set of nanostructures, which can be considered as quantum analogues to an optical interferometer with a beam splitter. Superconducting (Al) loop is connected to a normal metal electrode (Cu) through a tunnel barrier. Tunnel current at fixed bias voltage is periodically modulated by perpendicular magnetic field. The magnitude of oscillations reaches almost 100% at sufficiently low temperatures close to the gap energy. Another geometry, a superconducting fork shorted by a normal metal bar through two tunnel barriers has also been studied. The tunnel current appeared to be a periodic function of the perpendicular magnetic field, and/or voltage between the NIS junctions. The second system can be considered as an analogue to a double slit optical interferometer.

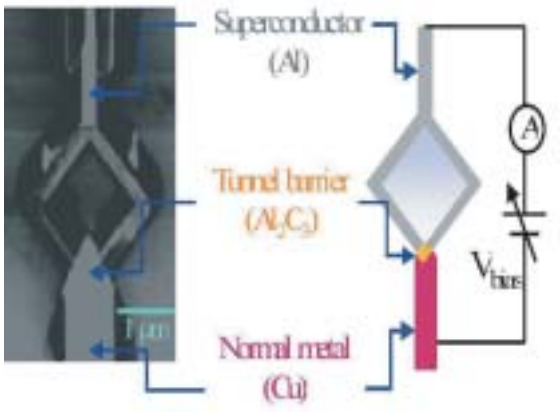


Fig 5. A SEM micrograph of a superconducting interferometer, and a schematic of the measurement.

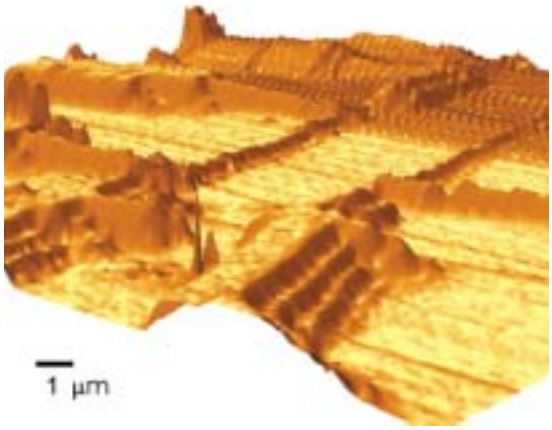


Fig 6. An AFM image of a sample with nanowires.

Method of progressive reduction of a metallic nanowire diameter has been proposed. A lift-off fabricated nanowire is etched in low-energy DC argon plasma, with a reasonable etching speed of 2 - 5 nm/ min. AFM control of the surface was used throughout the process. The etching has a polishing effect smoothing the initially imperfect surface of a microstructure. The method is applied for experimental study of the quantum phase slip effect in ultra-thin superconducting wires.

Ferromagnetic ion implantation was shown to be a useful tool to reduce the superconducting critical temperature of aluminum-based nanostructures. The work was done in collaboration with Nanoway Oy and the Accelerator-based material science group.

Tunnel junctions: modelling and applications

Modelling and measurements of tunnel junction characteristics

Tunnel junctions are very important in the application of nanoelectronics. In spite of this, there does not exist a well established theory to explain several important facts about their properties. Also, fabrication procedures are mainly based on empirical rules. We have recently developed a semiclassical model to explain the bias and temperature dependence of the tunneling current and conductance in normal metal—insulator—normal metal (NIN) tunnel junctions. The model explains correctly the observed temperature dependence of the tunneling conductance in the region between 4.2 K and room temperature.

The model was developed in parallel with experiments. Measurements of zero bias conductance and conductance vs. bias were performed on a number of Al—AlOx—Al tunnel junctions, in the temperature range 4.2 K to ~295 K. The theory and experiments combined yield several absolute quantities, which characterize the tunnel junctions. From our model we obtain all the required information to determine the fundamental junction parameters: thickness and height of the tunneling barrier and the dielectric constant of the insulator.

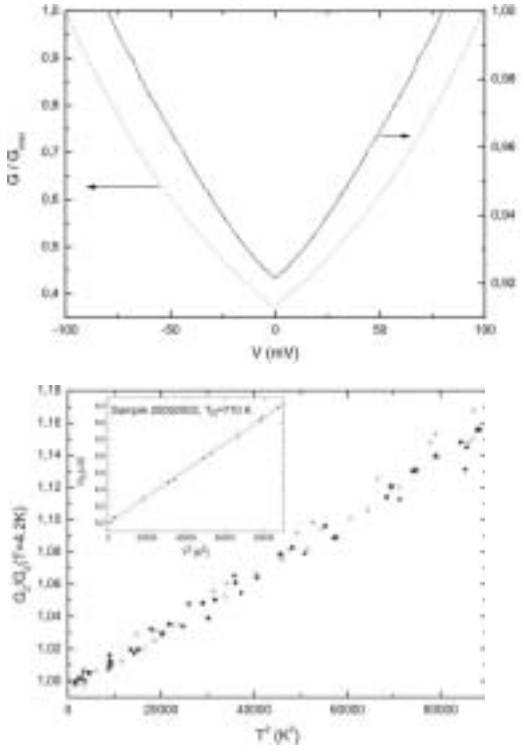


Fig 7. The tunneling conductance of a NIN junction as a function of the bias voltage (top), compared with the model (dashed line). Right figure shows the zero bias conductance temperature dependence.

Development of Coulomb blockade thermometry

The areas where Jyväskylä has gained a leading role world wide, namely CBT thermometry and NIS- microrefrigeration, continue to be studied and applied. The CBT development is conducted in close collaboration with Nanoway Oy, who has commercialized the CBT technology into a working primary nanoscale thermometer. In 2002 the stability of the sensors were improved by using a heat resistant PES (polyphenylen-ether-sulphone) based resists, which allows contamination-free patterning. Also, thermalization of the electron gas has been improved by enlarging the island volume, and accurate (to 8 %) operation of the sensor down to 20 mK has been possible. These measurements were performed in collaboration with CNRS/CRTBT in Grenoble, France.

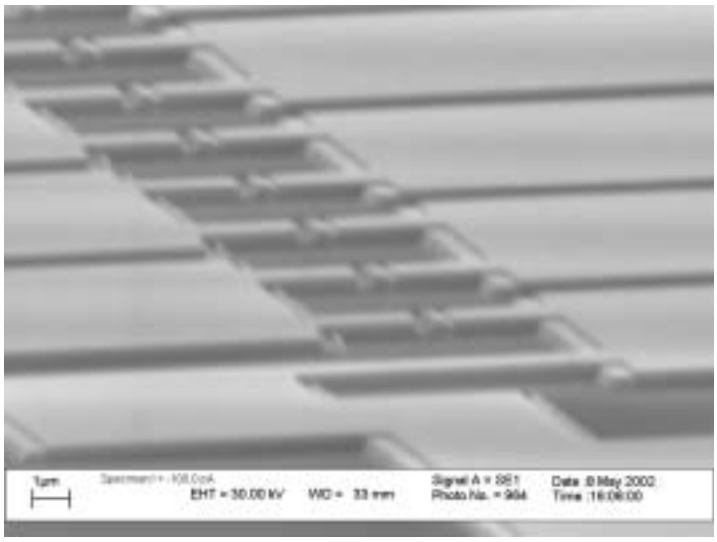


Fig 8. An SEM image of a CBT array with large island volumes.

Nanoelectronics and nanotechnology

Päivi Törmä

Experimental Research

DNA detection sensor

There are many suggestions of using DNA as a molecular wire in the electrical circuits, where the self-assembly properties of DNA molecule could be exploited. Electrical properties of DNA molecule have been studied widely over the world, but the experimental results seem very controversial. According to some recent results the double helix DNA is found to be a good semiconductor whereas a single-stranded DNA is known to be an insulator (See Fig. 1). This property of DNA molecule can be used in electrical identification of unknown DNA sequences.

At present the thickness of deposited material layers can be controlled very accurately, which gives us a good vertical resolution. In the DNA detection sensor the vertical edges of the metal-insulator multi-layer structure acts as a functional region. DNA molecules (of length 20-100nm) are to be attached between two vertical metal plates, which are separated by the insulator layer. Attaching of the perfect double helix DNA should be observed by measuring the conductivity between plates. Possible mutations in the double helix structure should critically decrease the conductivity.

We have been considering and testing the possibilities of different fabrication and measuring techniques. Electron beam evaporation is found to be suitable technique for thin metal film deposition. Supply of Chemical Vapor Deposition equipment, which would be optimal for the deposition of high quality insulator layers, is under consideration. The project is in collaboration with the Department of Chemistry and the Department of Biological and Environmental Science.

Nanosensors for temperature

We have developed a method for suppressing superconductivity of thin films. Thin stripes of cobalt were placed in the vicinity of aluminium thin film structures. The cobalt stripes were magnetized at 4.2 K and the remanence

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Timo Koponen, MSc student
Ossi Partanen, MSc student
Tarmo Suppula, MSc student
Tuula Kerkkänen, trainee

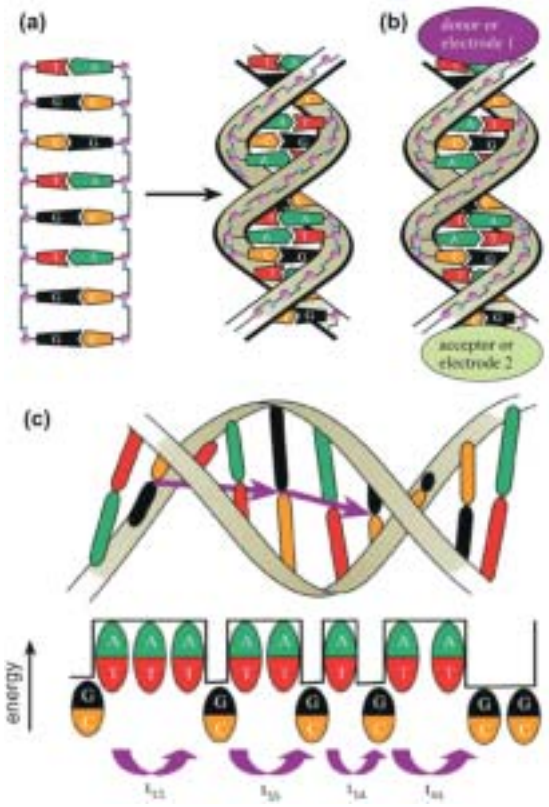


Fig. 1. Forming of the conducting double helix DNA. (a) Two complementary amino acid sequences of single DNA strands bond together with the hydrogen bonds forming the double helix structure. (b) DNA is connected between electrodes in the different potential. (c) Electron transfer mechanism through the double helix DNA.

suppressed superconductivity of the Al stripe at temperatures down to 50 mK at least. The magnetization remained in thermal cycling and in a longer storage at room temperature. The method enables the use of Coulomb Blockade Thermometer (CBT) (Product of Nanoway Ltd.) without external magnetic field by maintaining its junction in a normal state below the critical temperature of aluminium (T_c=1.4K) (Fig. 2).

We have also started a project for developing biosensors to measure and control the temperature of single living cells cultured on silicon chips. This project is a collaboration with Nanoway Ltd and the Department of Biological and Environmental Science.

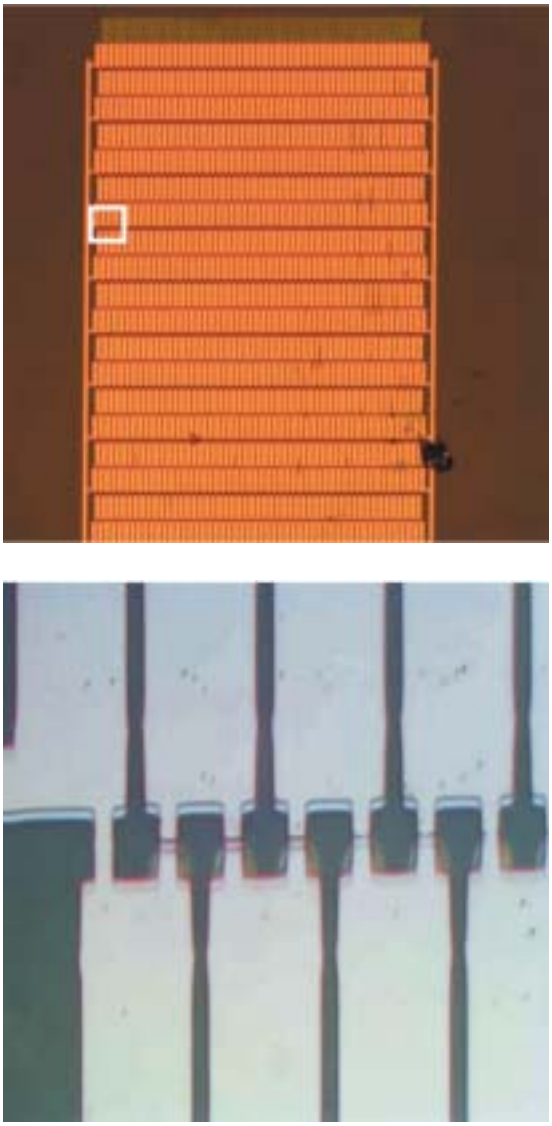


Fig. 2. A CBT with 10x100 junctions fabricated on cobalt stripes (top). A detail of the structure (bottom) shows CBT junctions on the edge of the cobalt stripes (the area indicated with the square on the top is magnified at the bottom).

Chemical sensors

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

Sensors for electric current

The aim of the research is to develop miniaturised sensors for measuring electric current and magnetic field. We have studied different techniques and manufactured e.g. a Hall effect-based and a flux gate sensors (see Fig. 3). A finite element method (FEM) –based software has been used for developing microelements and prototypes have been fabricated using electron beam lithographic technique. The research has been done in cooperation with industry.

Fig 3. A microscope image showing a flux gate sensor element used to measure magnetic field. Two nested coils have been patterned using 10mm line width. Ferromagnetic material has been used as a core for the coils. The core and the coils have been separated with insulating layers.

Efficient electronic cooling and electron-phonon coupling in heavily doped silicon

Efficient electronic cooling based on semiconductor-superconductor-semiconductor (S-Sm-S) junctions at low

temperature is a promising technology for sensor applications and in particular for hot electron bolometers. In this structure there is no insulating layer as in NIS-structures, because at the interface between the semiconductor and the superconductor a Schottky barrier is formed. This enables the operation of the cooler: at proper bias voltage (V < De) the tunnelling of "hot" electrons (with $E > E_f$) from heavily doped silicon into superconductor and the tunnelling of "cold" quasiparticles (with $E < E_f$) from superconductor into silicon result in cooling of the electron system in heavily doped silicon.

In order to improve the operation of the cooler the doping level can be varied. The cooling efficiency is shown in Fig. 4 as a function of temperature with four different doping levels. As the doping level increases the cooling efficiency starts to decrease. According to results of our numerical modelling the observed behaviour cannot be described by back tunnelling of hot quasiparticles and phonons. Therefore it is likely that the Joule heat produced by leak current through ohmic areas of the junction is responsible for this deterioration of the cooling power.

Another approach to indirectly affect the cooling efficiency is to modify the electron-phonon interaction. The electron-phonon interaction determines the heat flow between electron and phonon systems and it increases with the carrier concentration (see Fig. 5). When we overheat the electron gas in thin heavily doped silicon film above the substrate temperature the lattice is also heated and this lattice overheating must be taken into account in the analysis. The heat transport from electron system to phonon system is proportional to T^6, which is according to theoretical results. The research is a collaboration with VTT Microelectronics.

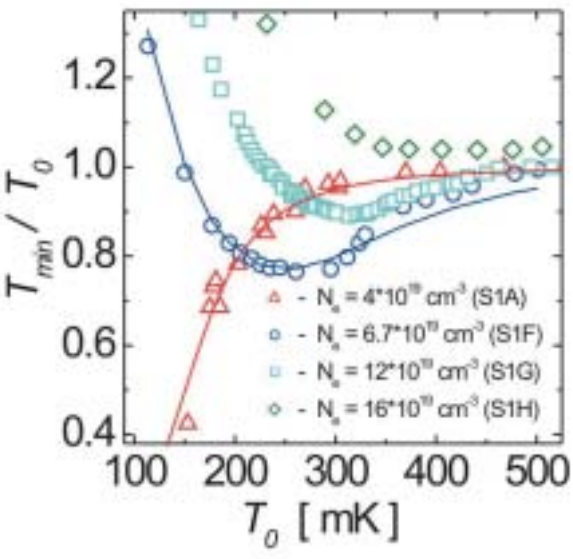


Fig. 4. Minimum relative electron gas temperature in the S-Sm-S cooler as a function of the substrate temperature. Electron gas temperatures of samples with different carrier concentrations (N = 4•10^{19} cm^{-3} - 16•10^{19} cm^{-3}) are plotted with red, blue, cyan and green colors. The cooler with the lowest carrier concentration (red triangles, N = 4•10^{19} cm^{-3}) is able to reach 65 mK electron gas temperature at 150 mK substrate temperature. The solid lines correspond to theoretical results, where Joule heat by leak current in the S-Sm junction is considered.

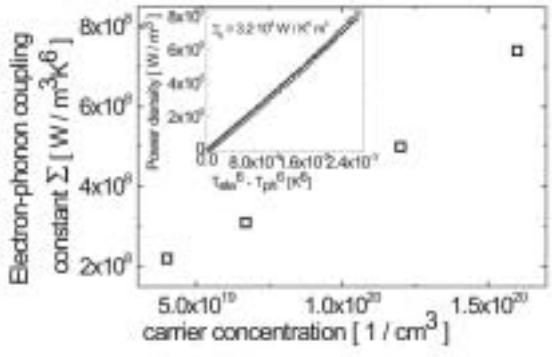


Fig. 5. The electron-phonon coupling constant as a function of the carrier concentration. Inset: power density is plotted against (T_e^6-T_{ph}^6) for the sample with a doping level of 6.7•10^{19} cm^{-3}. The electron-phonon coupling constant (Σ = 3.2 • 10^8 W/m^{3}K^6) is derived from the slope of the graph.

Theory Research

The success of Bose-Einstein condensation (BEC) in alkali gases has inspired the trapping and cooling of also the fermionic isotopes. Diluteness and the weak interaction of atomic gases offer ideal tools for studying fundamental quantum statistical and many-body physics.The most prominent phenomena for fermionic samples would be the superfluid BCS transition. Trapped fermionic atoms in different hyperfine states may have an attractive interaction caused by s-wave scattering. According to theoretical predictions, the system lowers its energy by forming atomic Cooper pairs and becoming a superfluid.

The vortex core size reflects the typical coherence length of the system. We have analyzed the single vortex solution for the order parameter very close to the transition temperature, and we found that the healing length differs from that of bulk metallic superconductors due to the trapping effects.

We have proposed the use of on- or near-resonant light to excite collective modes and to probe the order parameter in order to detect the superfluid transition and the Cooper-pair coherence. We have also considered an ana-

Fig 6. The fabrication of microelements with a scanning electron microscope in progress.

log of the internal Josephson effect in superfluid atomic Fermi-gases and found an asymmetric below-gap tunneling effect with no analogue in the context of solid-state superconductivity, see Fig. 7.

Fermi gases loaded in periodic optical potential (optical lattice) can also be used to observe purely quantum transport phenomena such as Bloch oscillations. We are also studying the possibility of simulating models of high-T_c superconductors with atoms in optical lattices. The effect of interaction between the CuO-planes in cuprates and the roles of s- and d-wave scatterings can be analyzed by modifying the optical potential. Therefore the system can work as a test ground for different theories.

Photonic crystals

Photonic crystals are periodic dielectric structures. The periodicity causes bandgaps for light, i.e., light in a certain wavelength region cannot propagate in the crystal. The periodicity, and thus the bandgap, can be in either one, two or three dimensions. A typical example of a one-dimensional photonic crystal is the Bragg grating. Two-dimensional photonic crystals embedded with defects could be used e.g. as a waveguide for integrated optics and three-dimensional photonic crystals as a microcavity.

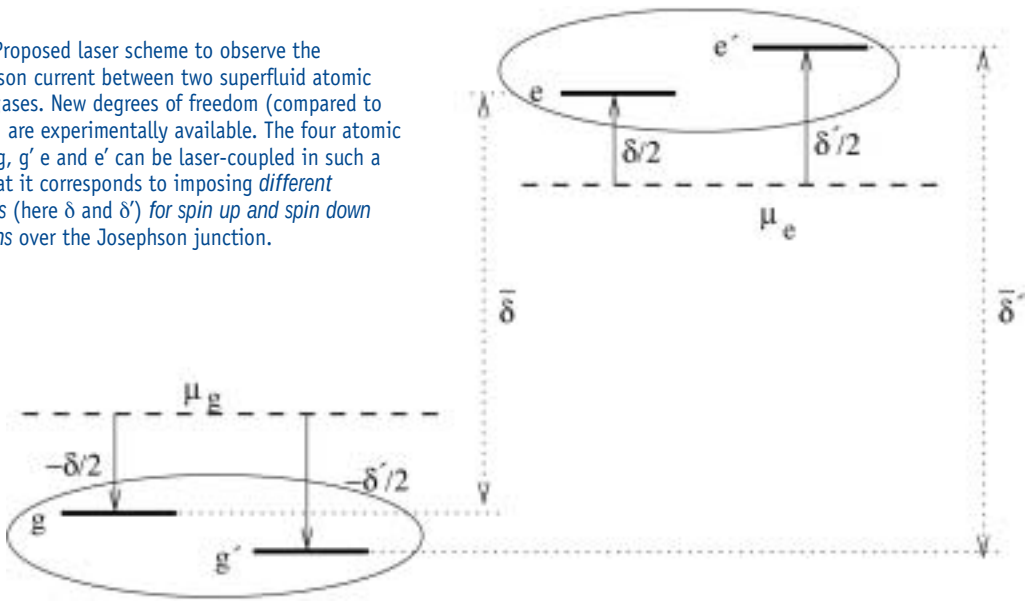


Fig 7. Proposed laser scheme to observe the Josephson current between two superfluid atomic Fermi gases. New degrees of freedom (compared to metals) are experimentally available. The four atomic states g, g′ e and e′ can be laser-coupled in such a way that it corresponds to imposing *different voltages* (here δ and δ′) *for spin up and spin down electrons* over the Josephson junction.

Photonic crystals are a very attractive solution to various problems in telecommunications and may become the key material for integrated optics. To this end they are required to be as small as possible. Therefore we study thin slabs of one- and two-dimensional photonic crystals and the coupling of nearby waveguides composed of photonic crystals. We also study photonic crystals made of Kerr-nonlinear materials, which means that the material properties are dependent on the local light intensity.

We have developed an iterative Fourier-method to calculate the bandstructures. In order to study the propagation of light in the structures mentioned above we use a finite difference time domain (FDTD) method developed in collaboration with VTT Electronics.

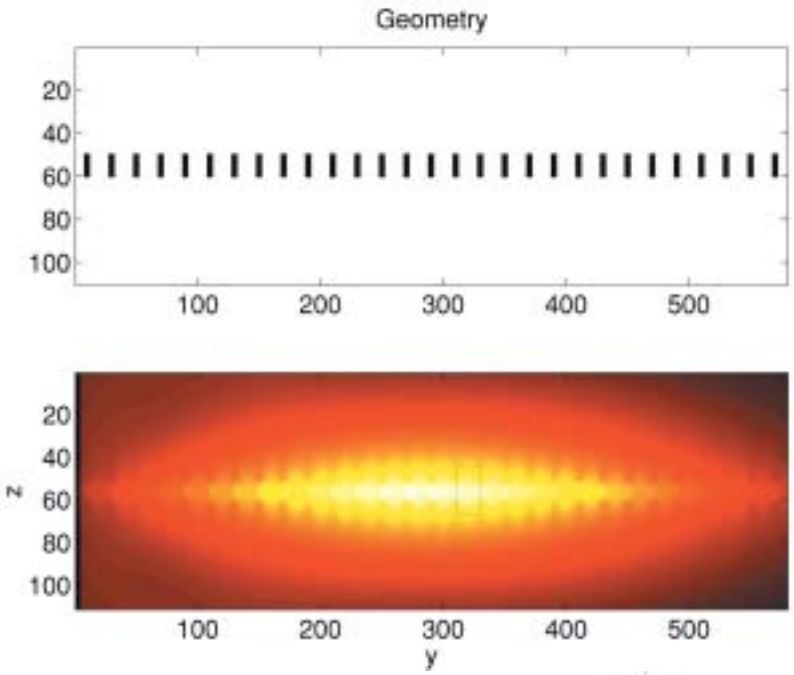
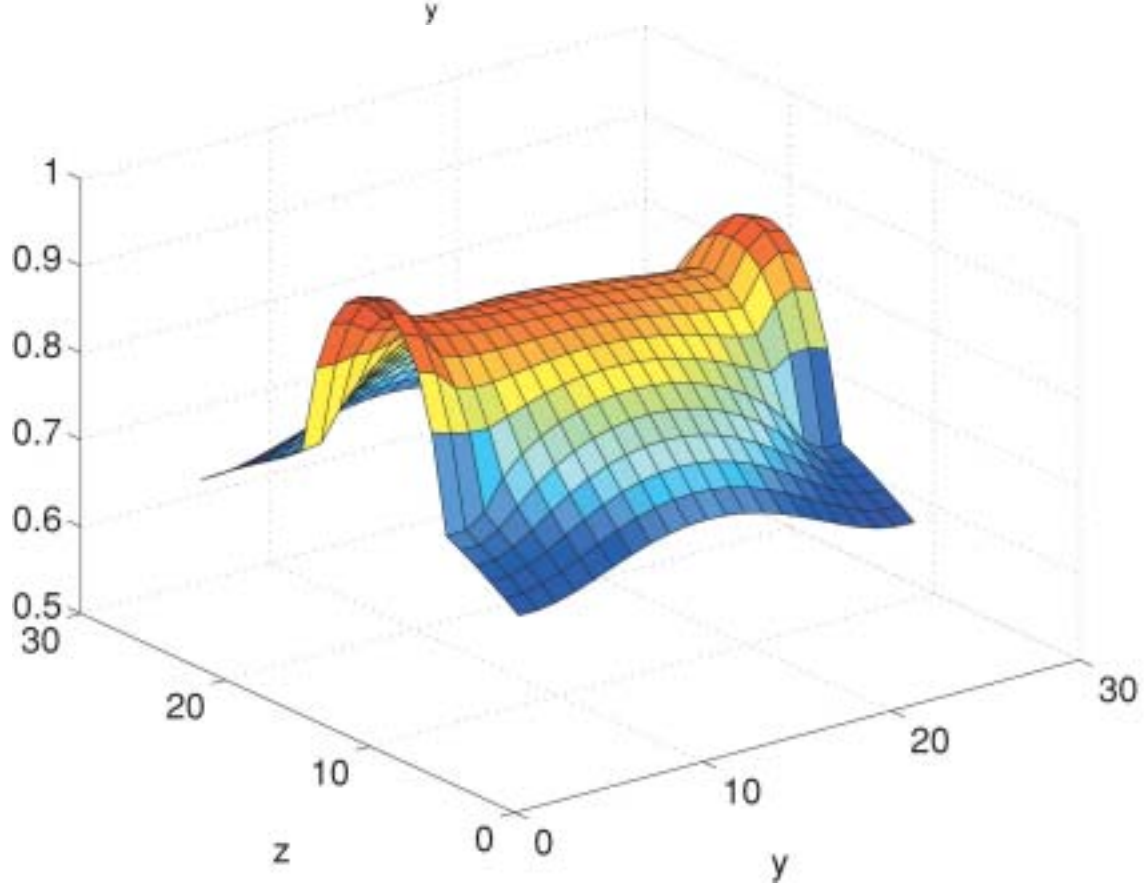


Fig 8. Above, cross section of a one-dimensional photonic crystal slab and a Gaussian pulse propagating along it. Below, the shape of one component of the eigenmode in the region marked with a square.



Quantum information

Nanoscale devices such as Cooper pair boxes or coupled quantum dots have been suggested as scalable realisations of quantum bits. We study theoretically the use of a superconducting single-electron transistor (SET) as a quantum measurement device. Coupling the charge qubit with the transistor allows one to distinguish the two qubit states by observing the conductance in the SET. On the other hand, in the absence of bias voltage, no dissipative current flows through the system and the quantum coherence of the qubit is preserved.

One can also design quantum wires and wells by bringing atoms close to magnetic fields created by current-carrying wires and external electric fields. We are studying quantum coherence in Y-shaped atom guides in collaboration with the Metrology Research Institute and the Laboratory of Optics and Molecular Materials of Helsinki University of Technology.

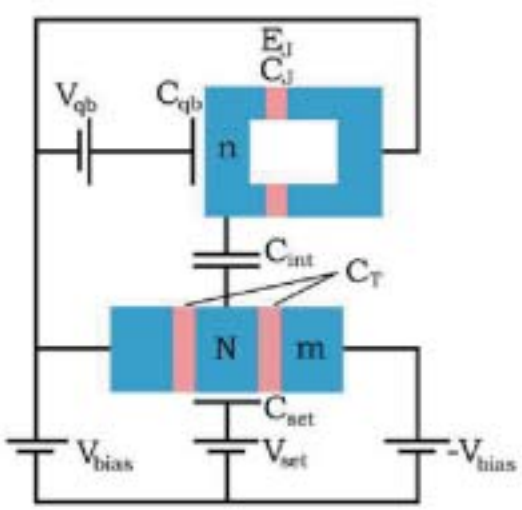


Fig 9.The state of a Cooper pair charge qubit affects the current in the coupled single-electron transistor. Thus, the transistor can be used as a measurement device for the charge qubit by switching on the bias voltage and measuring the current.

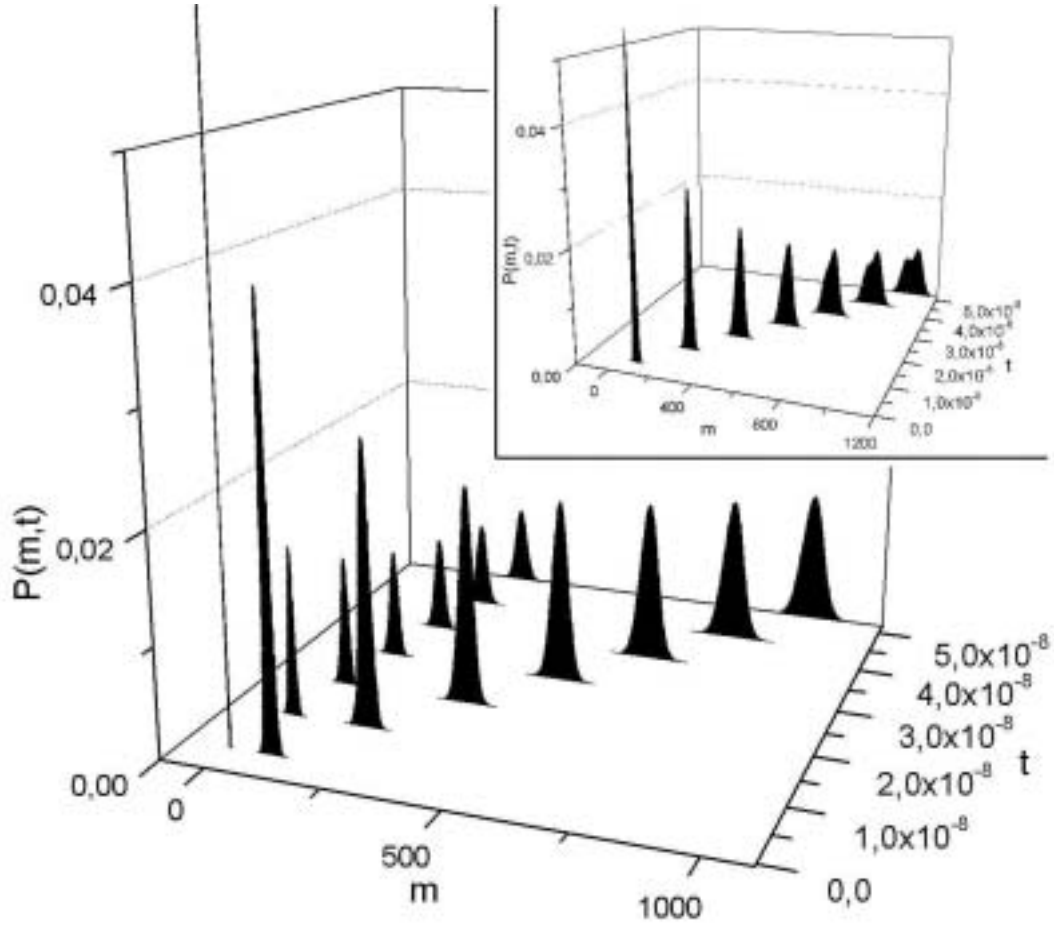


Fig 10. The two conductance peaks of the transistor, corresponding to different states of the qubit, gradually separate. The state of the qubit is measured once the two conductance peaks can be distinguished. The inset shows the corresponding time evolution for a normal-metal transistor.

Atomic clusters and quantum dots

Matti Manninen

Electronic and ionic structure and geometry of metal clusters. Density functional theory with ab initio pseudopotentials is used to study the electronic structure and stability of large aluminium clusters containing up to 110 atoms. Initial cluster geometries are generated from close-packed structures obtained with Monte Carlo methods. Stacking faults are allowed in the trial structures. Ab initio electronic calculations are used in the final relaxation of atoms. The calculated photoemission stpectra of many of the low energy isomers are in fair agreement with experiments. The results indicate that already quite small aluminium clusters favour the FCC structrure of the bulk instead of the icosahedral structure which is common for other metal clusters.

Clusters on surfaces. Car-Parrinello technique is used to study graphite surfaces using small clusters and infinite surfaces in a periodic supercell. The goal is to study alkali metal clusters on the graphite surface. Preliminary results show that two or three graphite layers are enough to obtain the diffusion barriers for a single sodium atom on the surface. In the future we will study the effects of the surface on the geometry and electronic structure of two-dimensional clusters on graphite and the penetration of alkali atoms between the graphite layers.

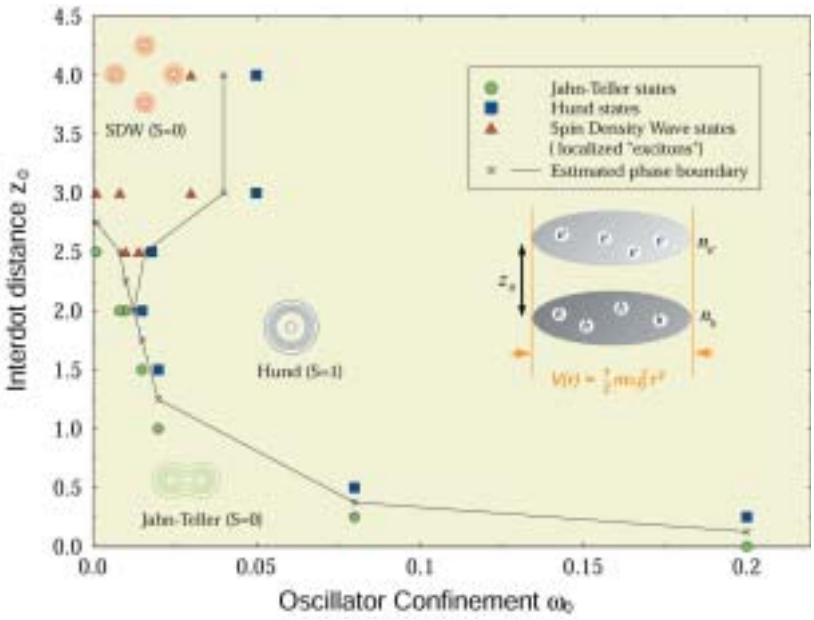


Fig 1. Phase diagram of electron-hole double dots with four electron and holes. The horisontal axis shows the strength of the harmonic confinement and the vertical axis the distance between the dots. Examples of the particle densities for the different phases are shown in insets.

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Cluster melting. Classical and ab initio Molecular dynamics is used to study melting of small sodium clusters. Semiclassical model potentials are found to give size-dependent melting temperature, but the maxima and minima of the melting temperature as a function of the cluster size do not agree with the experiments. This suggests that ab initio techniques are needed for the detailed understanding of the melting of small metal clusters. Our studies of the effect of bulk and surface melting on the ionization potential show that the effects of the electronic structure can not be neglected. In the near future ab initio molecular dynamics will be used to study the dependence of the melting temperature on the cluster size.

Double quantum dots. Density functional theory is used to study vertical double dots. In an electron-hole double dot one dot is filled with electrons and one with holes. In this case there is an attractive interaction between the particles in separate dots. At small distances the electron-hole attraction dominates and the particle density becomes deformed, the shapes being determined by the ultimate jellium model. At intermediate distances the particle density will become circular and at large distances when the confinement potential is weak the electrons and holes form bound states which will have a repulsive dipolar interaction between them. Figure 1 shows the phase diagram of the electron-hole double dots with four particles in each dot. Electron-electron double dots will be studied including correlation effects between the electrons occupying different dots.

Dot lattices. We have used band structure technique with the local spin-density approximation to compute the electronic and magnetic structure of two-dimensional quantum dot lattices. In a single dot the magnetism is governed by the first Hund's rule. In a lattice of quantum dots the magnetic coupling is determined by the lattice structure, interdot distance and by the filling of the open shell in each single dot. The results show that in the case of a square lattice the coupling is antiferromagnetic if each dot has a half-full electron shell and ferromagnetic in other open shell cases. The result can be understood in the tight binding model with a rigid band approximation. Figure 1 shows the magnetic phase diagram of the square lattice of quantum dots.

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, for example, that the periodicity of the persistent current changes from ϕ_0 first to $\phi_0/2$ and eventually to ϕ_0/N when the ring gets narrower. We have used the Hubbard model and its Bethe ansatz solution to study the relation of the quasi-one-dimensional continuum rings to the strictly one-dimensional discrete rings. The results indicate that in one-dimensional systems the results for the persistent current are similar for both models. Figure 3 illustrates how the periodicity of the lowest energy state of the Hubbard model changes from ϕ_0 to ϕ_0/N when the contact interaction between the electron increases.

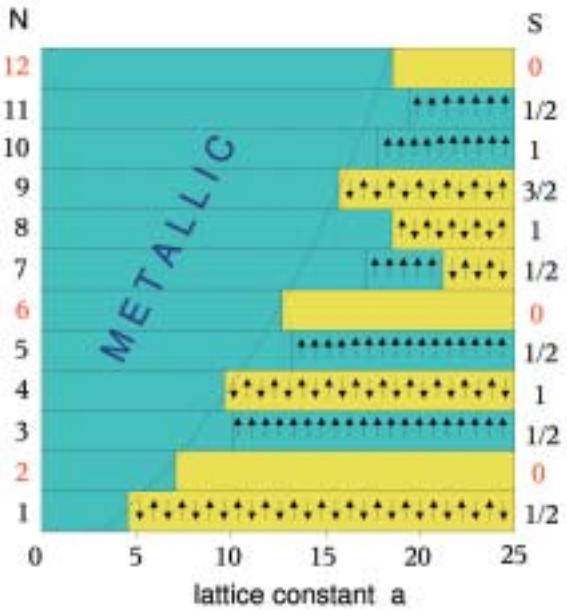

Fig 2. Magnetization of square lattice of quantum dots. N_d is the number of electrons in each dot and S the total spin in an isolated dot. Blue color shows the metallic and yellow the insulating phase. The magnetic structures are shown with arrows.

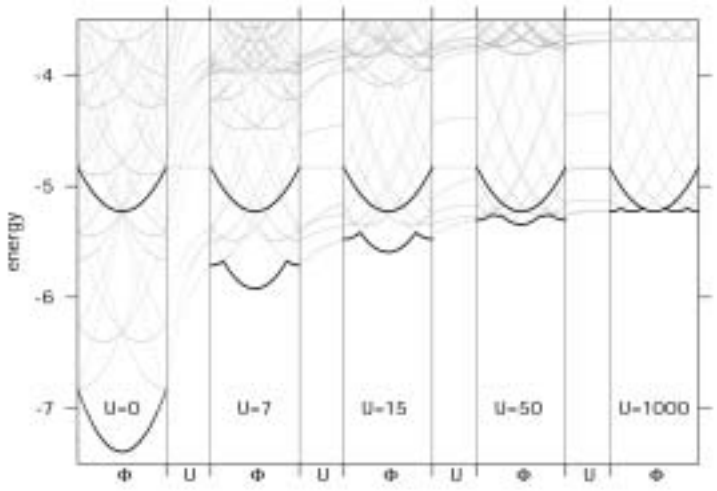

Fig 3. Energy spectrum of four electrons in a ring of eight sites. The ground state energy and the lowest energy state of the maximum spin are shown with thick lines. Note that the maximum spin state is independent of the intraction strength U.

Disordered materials and nonlinear physics

Jussi Timonen and Markku Kataja

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

The main areas of research in this group were elasticity and fracture of fibrous structures and random packings, dynamics of interfaces, flow in porous media and multiphase flows, and magnetic properties of small clusters of atoms. Applications were mostly in paper science and bone research.

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Jan Åström, senior scientist
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Elasticity and fracture of fibrous structures and random packings.

We used an inflated closed loop (membrane) to demonstrate a dynamic rigidity transition that occurs when impact energy is added to the loop in static equilibrium at zero temperature. The only relevant parameter in this transition is the ratio of the energy needed to collapse the loop and the impact energy. When this ratio is below a threshold value close to unity, the loop collapses into a high-entropy floppy state. The internal oscillations are in this state dominated by $1/f^2$ noise. When the ratio is above the threshold, the loop does not collapse, and its internal oscillations are dominated by the eigenfrequences of the stretched membrane. The dynamic transition between the floppy and the rigid state is discontinuous.

We have previously constructed an effective-medium theory for mats of randomly sedimented elastic fibres such that the stiffness of the mat depends on the properties of its constituents, and on a measure of its connectivity. A similar result can be found for random packings of elastic discs (2D) and spheres (3D). We have now shown that the same measures of connectivity together with geometrical properties of the constituents also determine the porosities of both types of materials. Evidently the key element for the description at this level of any material formed by random deposition is a measure of its connectivity.

Generic arguments and a numerical model were used to analyse the universal features of brittle fragmentation. Close to the minimum strain required for fragmentation, the number of fragments of size s scales as $s^{-(2D-1)/D}f(s/s_0)$ with D the spatial dimension and f a scaling function which is a constant for $s<<s_0$:s_0 diverges at the threshold strain. Above this threshold, f decays exponentially for $s>>s_0$. The scaling of s_0 is governed by disorder so that it does not show universal behaviour. At the threshold the density of cracks vanishes as $L^{-1/(D+1)}$ for increasing system size L. These results arise from random nucleation of cracks and consequent merging of crack branches, and they explain the empirical Gaudin-Schuhmann distribution.

Dynamics of interfaces

The spatial and temporal persistence were measured for slow-combustion fronts in paper. The stationary temporal and spatial persistence exponents were asymptotically found to agree with the predictions based on front dynamics in the KPZ universality class. The stationary short-range and the transient behaviour of the fronts were found not to agree with the predictions of Markovian theory. This deviation is related to additional time and length scales in the problem. This work included collaboration with Helsinki University of Technology.

A thin columnar defect affects an interface propagating in the medium. 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 (TASEP) with a slow or fast bond. For large positive difference in driving, the propagating interface develops a triangular shape with the slopes of its sides depending linearly on this difference. This behaviour demonstrates the existence of a KPZ type of nonlinear term in the equation of motion for the interface. For large positive difference in driving also the interface velocity is increased. This increase was found to disappear at a non-zero positive value of the difference. Simulations of the related TASEP model display very similar behaviour. They indicate that the disappearance of velocity increase is related to a continuous phase transition. This work included collaboration with the University of Washington in Seattle.

In order to further validate the description of propagating interfaces with the KPZ equation, we determined the coefficients of this equation, which best describe the time evolution and spatial behaviour observed for slow-combustion fronts in paper and magnetic flux fronts in thin-film high-T_c superconductors. Reconstruction of the relevant equation of motion and its coefficients was mainly based on the inverse method of Lam and Sander. The coefficient of the nonlinear term was also determined from the local slope-dependence of front velocity. This work included collaboration with the Vreije Universiteit in Amsterdam.

For a better understanding of the 'anomalous' short-range dynamics of slow-combustion fronts in paper, we used direct numerical solution of the KPZ equation with a noise term determined from beta-radiographs or optical scans of paper samples. The higher apparent scaling exponents at short time and length scales, and the spatial and temporal crossover scales to the asymptotic KPZ behaviour, were found to be mostly determined by the quenched disorder in the samples. Dynamical effects were found to be responsible for the power-law tail at short time scales in the amplitude distribution of the effective noise, and for the apparent multi-scaling of spatial and temporal correlations below the respective crossover scales.

We continued our work on particle systems with stochastic dynamics. Of particular interest were now models that can be mapped to those of propagating interfaces. Their extremal properties were studied both numerically and analytically. We also calculated the statistics of fitnesses for a generalisation of the Yee model, for which the limiting distribution functions were found using theorems for order statistics of independent random variables. Another related subject of study was diffusive transport of objects with internal degrees of freedom.

Flow in porous media

The lattice-Boltzmann method was used to compute flow properties of 3D porous materials such as paper and fabrics. The pore structures used in the simulations were obtained from realistic numerical modelling or from high-resolution x-ray tomographic images of actual samples. The results obtained indicate that the current resolution of x-ray tomography is sufficient for accurate computation of transport coefficients for fabrics. For paper the simulated values of permeability typically exceeded the measured values by a factor of two. This discrepancy is expected to arise from the insufficient resolution of tomographic images that did not show the fine structure of fibre surfaces. Analysis of high-resolution images by syncrothron radiation tomography is under way. This work included collaboration with the University of Minnesota in St. Paul.

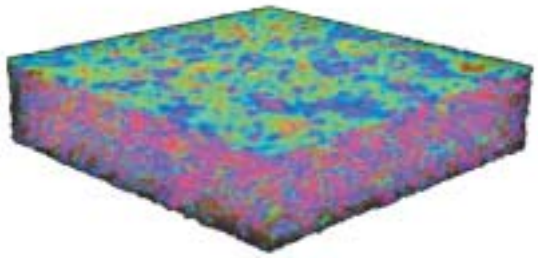


Fig 1. A tomographic image of a paper sample with colour coded flow field simulated by the lattice-Boltzmann method. Bright colours indicate high flow velocity.

Properties of suspension flows

The development of optical tomography for measuring concentration profiles in liquid-particle suspensions was continued. The first prototype device that includes 15 channels was found capable of imaging simple stationary objects, including samples that contain fibre suspension (Fig. 2). The construction of the second prototype was started. This device will be used to find the optimal construction and measuring techniques for the final multi-channel device meant for fast imaging of fibre suspension flows. This work included collaboration with the University of Kuopio.

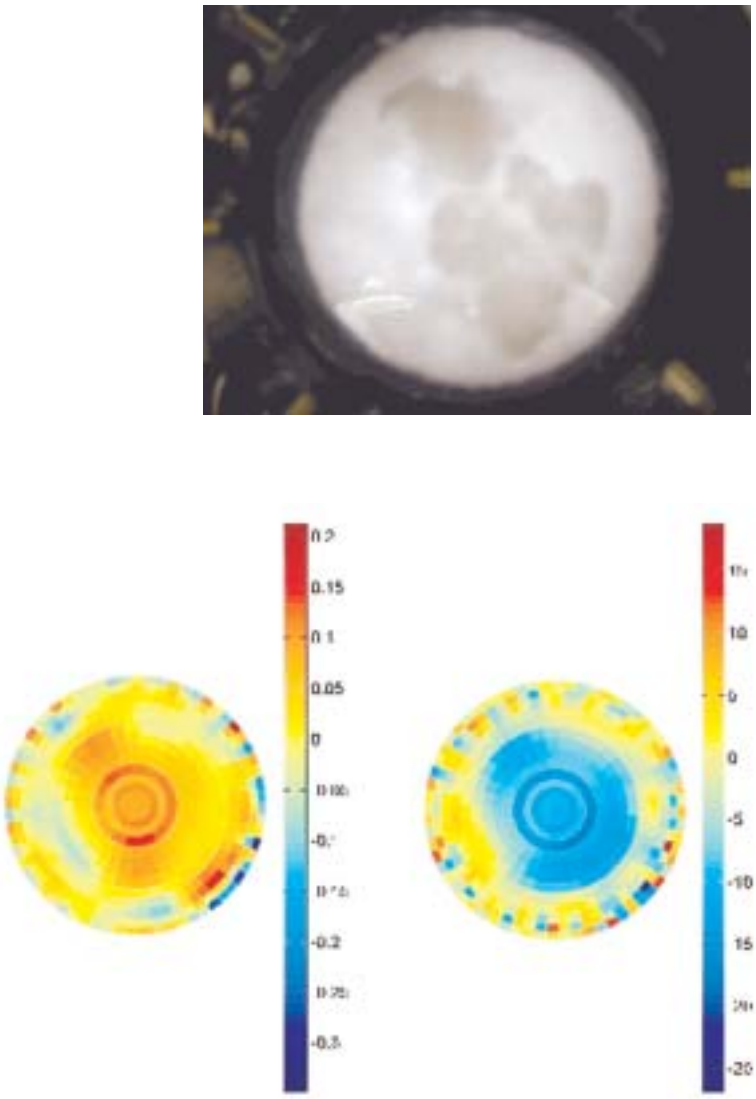


Fig 2. a) An image of a pulp sample with varying consistency. On the right are tomographic images of this sample based on the distribution of (b) absorption and (c) diffusion coefficients.

A shear flow of particle suspension between two plates (Couette flow) was analysed for the effect of particle clustering on viscosity. The clusters formed could be divided into rotating chainlike clusters, and layers of particles at the channel walls. The size distribution of the rotating clusters was scale invariant in the small-cluster regime, and decreased rapidly above a characteristic length scale that diverges at a jamming transition. The rheology of the suspension can qualitatively be divided into three regimes according to the particle Reynolds number (Re). In the small Re regime viscosity is controlled by the characteristic scale deduced from a generic particle-collision model. In the intermediate Re regime clustering is maximal, but onset of instabilities renders the generic model inapplicable. In this transition regime viscosity begins to increase. For large Re inertial effects become important, clusters begin to break up, and suspension displays shear thinning.

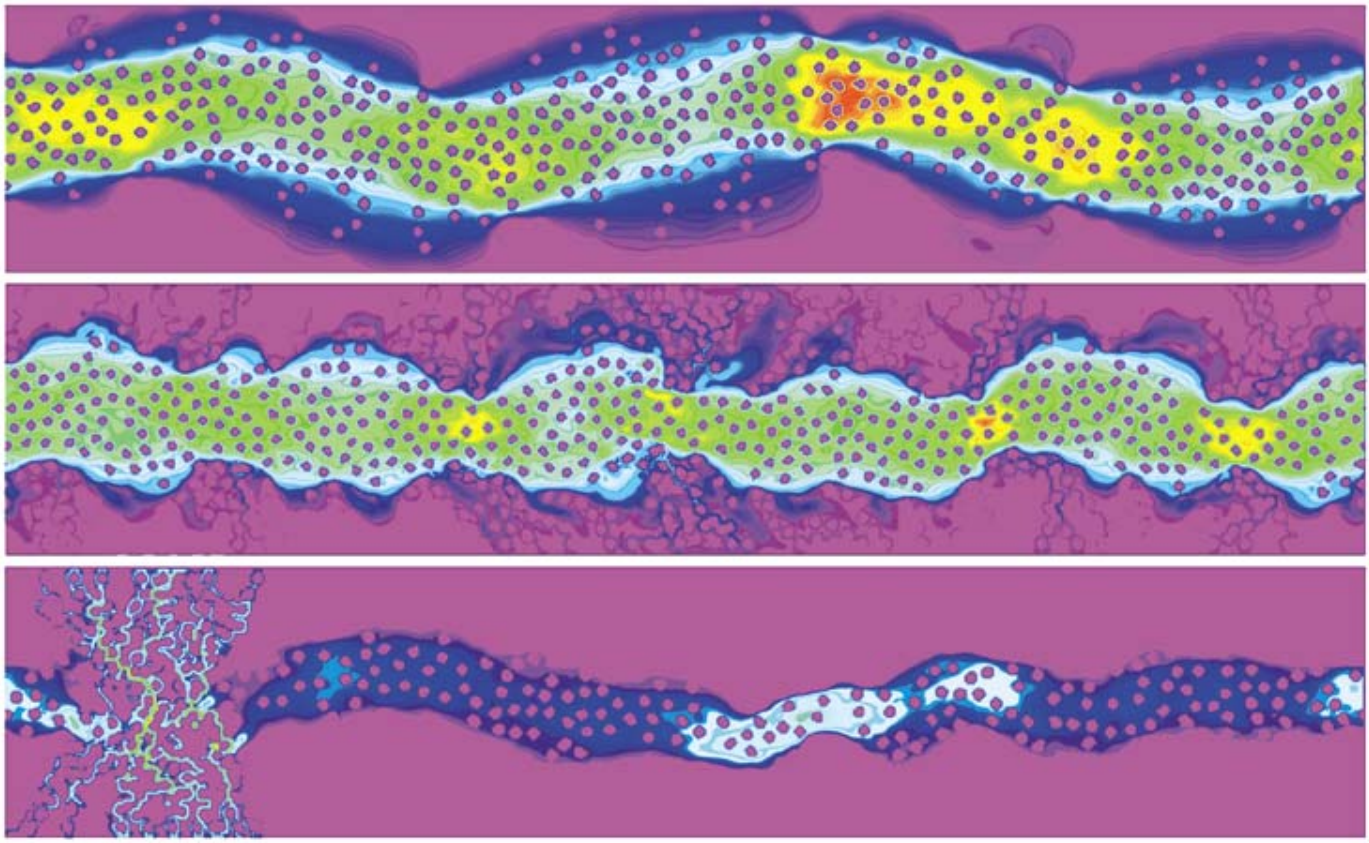
We also analysed particle suspensions flowing in a channel in which fouling layers were allowed to form on the channel wall, and determined its phase diagram with at least four different behaviours. Fouling was modelled by attachment if a suspended particle collided with a wall or a deposited layer, and by detachment of deposited particles if they felt a large enough hydrodynamic drag. The relevant parameters governing the dynamics are the solid volume fraction of the suspension and the detachment drag force threshold. Below a critical curve in the 2D phase space only transient fouling takes place. Above the transition curve, persistent fouling layers are formed via ballistic deposition for low and via homogeneous deposition for large solid volume fractions. Close to the transition curve, the flow path between the deposited layers meanders, while necking appears for increasing distance from the transition. Finally, another transition to a fully blocked flow path takes place. Both transitions seem to be discontinuous.

Applications in bone research

We compared low frequency ultrasonic guided wave measurements with established ultrasound and bone density measurements in terms of their ability to characterize human long bones. A prototype low frequency pulse transmission device including a uniaxial scanning mechanism was used to measure two ultrasound velocities in the tibia. The first velocity was that of the first arriving signal, while the second was that of a slower wave mode propagating at 1500-2000 m/s. We have shown previously that the bahaviour of the second mode is consistent with that of the lowest order antisymmetric guided mode. Bone mineral content, volumetric cortical density and cortical thickness of the tibia were measured using pQCT, site-matched to the ultrasound measurements. The measured velocities both correlated with the measured properties of the tibia. These results indicate that the prototype device reflects aspects of tibial cortical bone geometry in addition to bone density, thereby offering the potential of increased diagnostic information compared to existing tibial ultrasound devices. This work included collaboration with the Department of Health Science at the University of Jyväskylä.

Magnetic properties of small clusters of atoms

We studied the zero-temperature magnetization of small clusters in which the atoms are coupled by an isotropic Heisenberg antiferromagnetic interaction, and were interested in particular in the quantum to classical transition. From the energy spectrum of the system we obtained the magnetization curves as series of steps for finite spin length S. Each step was characterized by the space group symmetry of the cluster and many different representations may be present. In the classical limit S ->∞ and then magnetization curves are typically piecewise smooth curves or straight lines. We find two basic types of behaviour, depending on whether or not the steps are characterized by a single or many different representations. This latter case is associated with extra hidden symmetry. This work included collaboration with UMIST in Manchester and the University of Oxford.



High energy physics

Ultrarelativistic heavy ion collisions

Vesa Ruuskanen and Kari J. Eskola

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

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 quite intense. The successful start of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven in summer 2000 and the anticipation of the ALICE experiment at the CERN Large Hadron Collider (LHC) in 2007 has inspired and strengthened also the theoretical work on URHIC. Our goal in the theoretical and phenomenological studies of nuclear collisions has been (1) to predict the primary production using next-to-leading order perturbative QCD (pQCD) and the conjecture of gluon saturation, (2) to describe the evolution of produced matter from the calculated initial state to final free hadrons by applying hydrodynamics, (3) to obtain hadron spectra, as well as the integrated observables from the hydrodynamic calculation, (4) to study hard processes in hadronic and nuclear collisions by applying pQCD, and (5) to apply the hydrodynamical model in the calculation of thermal emission of electromagnetic signals.

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 (K. Kajantie) at the Department of Physical Sciences, University of Helsinki. We are also in close contact with the ALICE group at JYFL. Internationally, in addition to running an active visitor program, we have collaborated with researchers from CERN/TH (Geneve), Nordita (Copenhagen) and LAPPTH (Annecy) in Europe, and from the Lawrence Berkeley National Laboratory, the University of Minnesota, and the Iowa State University in the USA. We have also actively participated in the work and organization of the series of CERN Hard Probes international workshops at the CERN/TH, and in an INTAS project.

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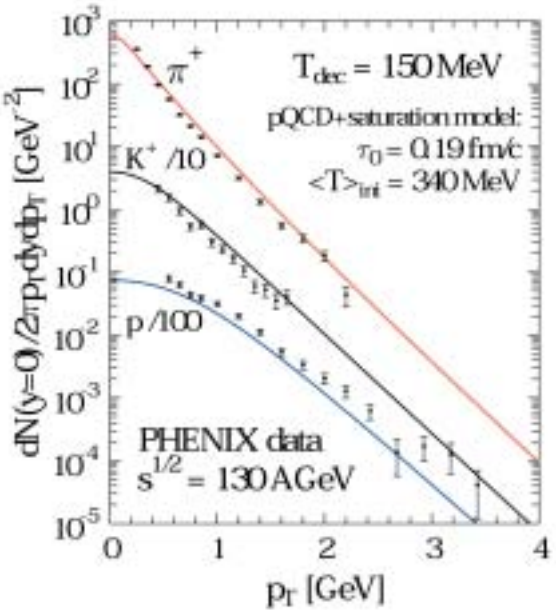
Initial state of the QGP from pQCD and saturation: The initial densities of the QGP produced in *AA* collisions at RHIC and LHC can be estimated on the basis of calculable parton production. Gluons and quarks with transverse momenta in the range of few GeV, minijets, are expected to dominate the formation of the QGP at collider energies, and production of such quanta can be computed by using perturbative Quantum Chromodynamics (pQCD). Calculation of infra-red safe quantities, such as the transverse energy and net baryon number carried by the minijets above a minimum transverse momentum scale, are also extendable to next-to-leading order (NLO). Especially, our estimates of the energy densities lean on NLO pQCD. A further element needed for obtaining the initial densities, is gluon saturation: at sufficiently high gluon densities the production of gluons of smaller momenta becomes inhibited by gluon fusion (gluons are self-interacting); 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 on a formulation of the subsequent evolution of the QGP as a boost-invariant isentropic hydrodynamic evolution, we have correctly predicted the measured charged particle multiplicities $dN_{ch}/d\eta$ for Au+Au collisions at several cms energies at RHIC. We have analytically shown how the measured multiplicities probe the gluon densities of the colliding heavy nuclei at saturation. We have also further studied the rapidity dependence of the initial densities, charting the region of applicability of the ap-

proach. Computation of the initial net baryon number production and integrated minijet cross sections in NLO pQCD is in progress. Supercomputing has been provided by the Center for Scientific Computing (CSC, Finland).

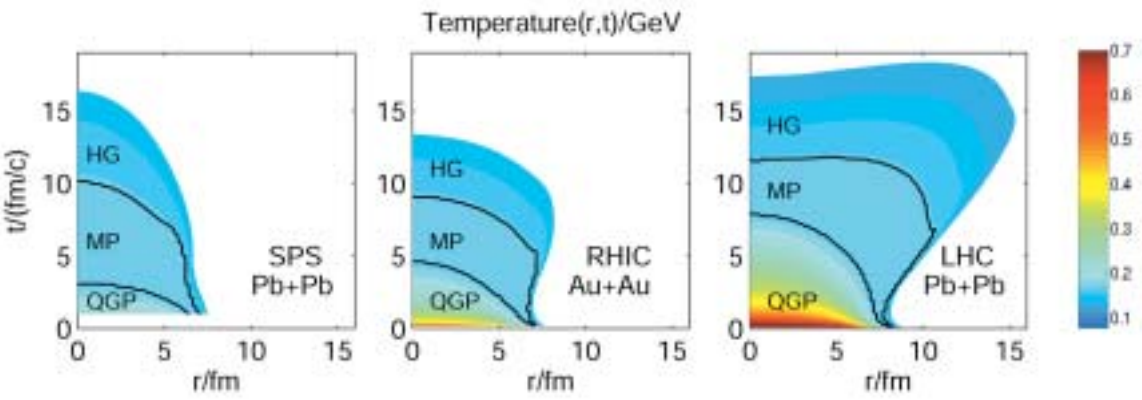


Hydrodynamical evolution of nuclear collisions: Abundant collisions taking place in the dense parton matter predicted from pQCD and gluon saturation will change the momentum distributions and lead to collective flow of final particles. Relativistic hydrodynamics provides a method to study the evolution of a locally thermal expanding system. Even though the hydrodynamic results on a system of nuclear size cannot be pushed too far, a strong feature in its favour is that conservation laws are automatically implemented. The main features of hadron spectra are shown to be well described. Also, it 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. In addition to showing that the final transverse energy is only about 1/3 of what is initially produced, we have demonstrated that the measured p_T-spectra of pions, kaons and (anti)protons are correctly reproduced when just a single, fairly high decoupling temperature T_{dec}=150...160 MeV is used (fig. 1). Thus, the hadron gas phase seems to be shorter than previously expected. Predictions for the LHC are to be published soon.

The measured hadron spectra are an indispensable constraint in pinning down the space-time evolution of the system. Once the spectra are under control, one may proceed to compute the signals from secondary collisions, the thermal signals, such as thermal photon and dilepton production. At SPS energy, we have calculated the spectrum of thermal photons using initial conditions constrained from the hadron spectra and the latest emission rates. The results show that the experimentally observed excess of photons over the known sources can be understood as photons emitted from the secondary collisions during the expansion of final state matter. At collider energies the situation with the thermal electromagnetic signals is more complicated due to the chemical imbalance of gluons and quarks. Studies on this topic have been initiated, also in connection with the CERN Hard Probes.

The azimuthal asymmetry of momentum distributions observed in non-central collisions at RHIC is most readily interpreted as evidence of formation of collective elliptic flow. The centrality dependence of the ellipticity v_2 of the flow is well explained by the hydrodynamical model up to transverse momenta close to 2 GeV. Detailed experimental data on elliptic flow, like the dependence



on particle species, are now becoming available. This provides tools for closer inspection of the space-time evolution of the collision and, promisingly, calculations show sensitivity on model details, like equation of state and freeze-out conditions. Work for relaxing the simplifications of azimuthal and longitudinal boost symmetry in the hydro codes is in progress.

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, such as production of direct photons and large-mass dileptons, are computable in a factorized form if the momentum scales Q^2 involved are large enough and if the number densities of different parton flavours in the colliding nuclei, the nuclear parton distributions (nPDF) are known. Also in the pQCD computation of the QGP initial state the nPDF are an essential ingredient. We have earlier determined the nPDF in a lowest-order pQCD (DGLAP) analysis by applying constraints from the measured structure functions F_2^A in deeply inelastic lepton-nucleus scatterings, the Drell-Yan cross sections in p*A*, and conservation of baryon number and momentum. A parametrization of the nuclear effects of the parton distributions, EKS98, is publicly available e.g. in the CERN routine library PDFLIB.

We are currently improving the statistical error analysis and extending the previous analysis to NLO pQCD. We have made further studies on how the measured momentum scale dependence of the ratio F_2^{Sn}/F_2^C constrains the nuclear effects in the gluon distributions: a strong gluon shadowing, a deficit of gluons at small momenta, seems to be ruled out. We have also studied in detail the effects of adding nonlinear terms in the DGLAP scale evolution equations of the parton distributions of the free proton. By using the recent HERA data from ep collisions as a constraint, our results show explicitly how the large corrections at few-GeV scales and small momenta vanish towards larger scales and larger momenta. Extension to nuclei and connection to gluon saturation have also been studied and further results are to be published. We have coordinated the work and the meetings of the subgroup on nPDF at the CERN Hard Probes.

Hadron spectra at high transverse momentum can be computed from pQCD when the nPDF and fragmentation functions of partons to hadrons are given. By analysing the spectra measured at pp and $p\bar{p}$ collisions at several cms energies, and by using the nPDF discussed above, we have computed the high-p_T hadron spectra for central and peripheral Au+Au collisions at RHIC. Comparison with the measurements at cms energy 130 *A*GeV shows a clear depletion from the computed pQCD reference spectrum. This may suggest that the high-momentum partons traversing the QGP exprience substantial energy losses. Further studies on parton energy losses, one of the most active topics currently in the field, have been launched. Comparison with the hydrodynamical results (see above) at RHIC and LHC will be reported soon.

Theoretical particle physics and cosmology

Jukka Maalampi and Kimmo Kainulainen

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-γ oscillations via atmospheric and solar neutrino measurements. Plenty of new experiments are in operation or under planning and much theoretical work is going on aiming to clarify and solve the fundamental questions associated with neutrinos and their interactions.

Our research has focused on the question of the origin of neutrino masses and mixings on one hand, and on the mass induced neutrino flavour oscillations on the other. 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 pysics related to it. In a scheme we have studied new interactions at some high energy scale generate small lepton number violating masses to neutrinos making the original Dirac neutrino to split into two Majorana neutrinos with a small mass difference. We have also studied the effects of the possible extra spatial dimensions on neutrino masses and mixings. Viability of these models was investigated by confronting them with the oscillation and other neutrino data.

Neutrinos play an important role in astrophysics and cosmology. One topical question in astrophysics is the origin of ultra high-energy cosmic rays (UHECRs). Neutrinos, which are created along with other particles in the active centers of galaxies and other cosmic ray sources, will carry direct information about the acceleration processes responsible on the creation of UHERCs. We have investigated the possible use of these neutrinos also in probing the basic properties of neutrinos and their interactions.

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. From these results it follows that the neutrino anomaly observed in the LSND experiment in Los Alamos 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" (Fig. 1) 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.

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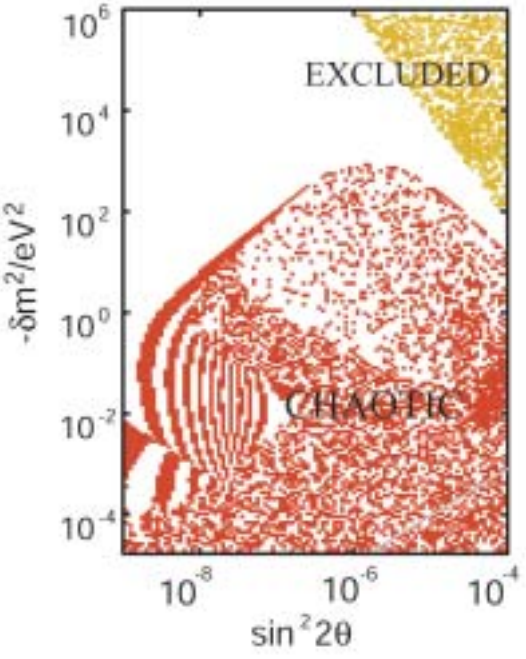

Fig. 1.

Baryon asymmetry: One of the most intriguing questions in modern cosmology concerns the origin of the baryon asymmetry, the observed 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 $(n\text{-}\bar{n})_L$ in front of the expanding wall (see fig. 2). 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 μ, which is readily accessible in the forthcoming particle physics experiments (fig.3).

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 non-equilibrium plasmas in spatially and temporally changing background fields. To this end we study the field theory within the Schwinger-Keldysh closed time path (CPT) formalism, which allows quantitative expansions in the Planck constant *h* (gradient expansion) and in coupling constants. Among our results so far is the proof that the plasma has a single particle (spectral) limit to first order in *h*. This result contains dominant CP-violating effects relevant for baryogenesis and verifies the validity 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.

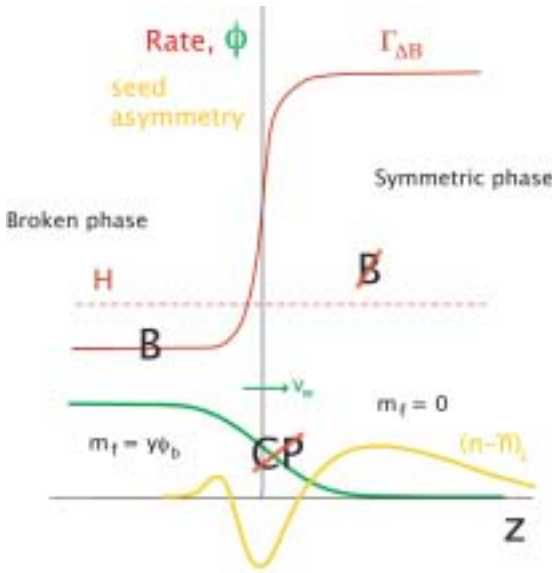

Fig. 2.

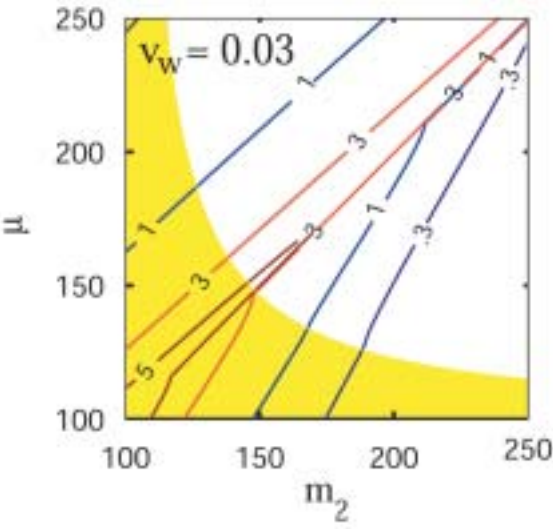

Fig. 3.

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 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 relationships 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.

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ALICE experiment at CERN

Wladyslaw Trzaska

http://www.hip.fi/research/nucmat/index.html

ALICE – centered research is funded and organized within the structures of Helsinki Institute of Physics (HIP) but it involves substantial human, laboratory and office resources from JYFL. The past year (2002) was marked by two major organizational changes of our project. The first was the elevation of our work within the internal HIP structures to the Project level. Regrettably, this change was not followed by the adequate increase in funding or by simplification of bureaucratic procedures. The second change, more important, was the final approval by ALICE collaboration of the new scheme of our core contribution. Core contribution is the direct hardware investment in the detector by each participating country. In case of Finland it was fixed at 1 million Swiss Franks. According to the initial agreement 90% of this amount was to be used for buying services from industry to bond the components of Inner Tracker System (ITS). The remaining 10% are the cash contribution to the common fund, as required from all participants. When the agreement was made the industrial option was the only viable solution. The completion of a suitable clean room in Kumpula Campus in 2001 combined with the delays in the bonding schedule have opened a new – albeit very daring – possibility: to move the Finnish share of bonding from the commercial companies to the Helsinki laboratory. To make it possible, three main goals had to be achieved: equipping in time of the new lab, finding highly qualified people, and winning of the final approval by the collaboration. We were able reach all of these goals. One can find more about this work from our HIP web-pages:
http://www.hip.fi/research/nucmat/index.html

The change in the bonding scheme generated considerable savings in the core expenditure. The savings could partially be used for funding of the T0 detector – the main timing and (fast) trigger detector for ALICE. In the present version T0 will consist of two arrays of 12 Cherenkov detectors with quartz radiators coupled to fine-mesh PMT tubes located at the opposite sides of the interaction point, close to the beam pipe. Due to extreme space constrains on the muon absorber side the two arrays cannot be placed symmetrically but will have the distance ratio of about 6:1 giving the pseudorapidity coverage $2.9 < \eta < 3.3$ for the closer array ($T0_R$), and $-5 < \eta < -4.5$ for the further array ($T0_L$). For the same reason the minimum distance for the fast analogue front-end electronics is about 5 m from the array. The toughest requirements in the design of T0 is the ability to operate in the 0.5 T field of the L3 magnet and to produce very good on-line timing with high efficiency not only for central Pb – Pb collisions but also for p – p collisions and minimum bias events. The former (operation in the magnetic field) limits the choice of PMT manufacturers to just two companies. The later imposes large (at least 1:200) dynamic range on the fast electronics and requires a very low threshold level of about 120 photoelectrons.

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Maxim Komogorov, scientist (HIP/JYFL)
Mariana Bondila, graduate student (HIP/JYFL)

Perhaps the most visible achievement during 2002 was the construction of a full-scale model of $T0_R$ properly equipped with PMT tubes, HV bases, quartz radiators, cables and optical fibers for laser calibrations. The model was built to optimize the light-weight carbon fiber construction, perform the necessary weight-load tests on it, and aid in the integration of the other detectors and services in the congested space between the interaction point and the muon absorber. The model will also serve as the ideal detector support for in-beam tests at CERN that are scheduled for 2003. There was also a major progress on the design of the front-end electronics. T0 collaboration has completed 3 independent prototypes of the amplifier/discriminator stage. The first tests with laser and pulse generators indicate that for each prototype we were able to reach less than 50 ps time walk over nearly 3 orders of magnitude of input amplitude. The design work and tests will continue throughout the next year as well.

The third field of activity of our team is software. Over the past year we have worked on two directions: software design and maintenance, and development of algorithms and benchmark studies of detector performance for the Inner Tracking System (ITS) of ALICE. As physics

analysis is our final goal we have gradually shifted our efforts towards the development of algorithms for the reconstruction of the kink decays (in TPC). This will lead naturally to the evaluation of how well the ALICE detector can measure the strange particle production which in turn play an important role in revealing the production mechanisms in relativistic heavy-ion collisions.

Industrial collaboration

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

Industrial contacts related to *accelerator physics*: Completely new international co-operators last year were Centre National d'Etudes Spatiales, CNES, The French Aeronautics and Space Research Center, ONERA, both from Toulouse, France, and the University of Århus. Together with Patria New Technologies Ltd. from Tampere, Finland, their primary target was to study the impact of heavy ions on the processor performance and to get confidence that the SEE sensitivity of the device is acceptable for the RØMER mission. RØMER is a Danish small satellite mission to study the oscillations of nearby stars.

Later last year also European Space Agency, ESA/ESTEC, together with HIREX Engineering Ltd., France, performed a SEE test in the RADEF sation. At the same time, preliminary planning for the upgrade phase of the JYFL-ESA contract was started. This was followed by an invitation of ESA's Industrial Policy Committee for all ESA member states to approve a Procurement Proposal to utilise the RADEF facility for component radiation studies. Also Tekes funded the project with the aim to prepare for the coming ESA contract and the exploitation of its commercial possibilities. The project belongs to Tekes' AVALI technology programme, which is formed to create business opportunities from space technology.

The research group from CERN and Helsinki Institute of Physics performed two tests in RADEF. In a short period the collaboration has generated many publications and proceedings presented in international conferences. The study is carried out in co-operation with Microelectronics Center and Electron Physics Laboratory from Helsinki University of Technology, Brookhaven National Laboratory, Upton, USA, a Finnish company Ocmetic Ltd. and recently also with the University of Warsaw.

The radiotherapy technology project funded by Tekes, Jyväskylä Science Park Ltd. and Acatec Ltd. was successfully finished. The finnish patent based on a new idea of γ-field profile detection, which was tested in the Department of Oncology of Tampere University Hospital and Jyväskylä Radiotherapy Hospital, was approved and an international PCT patent is pending. The R&D work will be performed by a new company, Gammapro Ltd., established in June 2002. Radef Research Ltd., a spin-off of JYFL, will participate in the new project.

The co-operation with Doseco Ltd. continued with a development of its multielectrode ion chamber system. The work was mainly done in co-operation with Jyväskylä Radiotheraphy Hospital. Also, the co-operation with MAP Medical Technologies Ltd. reached a sustainable status, because 40 commercial batches were produced during the last year. A study project with a Finnish paper company M-real Inc. also started. This was a first preliminary study for a future co-operation, where the aim is to develop a set of sensors to control a certain process in a new type production line.

The *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 a recent collaborative project has just started, 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 newly initiated *electronics research* in the department is establishing contacts with industry. The professorship in electronics is sponsored by local municipalities and industry, and an agreement about research and teaching collaboration was signed between Enermet company and University of Jyväskylä in 2000. The electronics group has at the moment one project funded by Tekes within the ELMO ("Miniatyrization of Electronics") research programme. The project focuses on micro- and nanosensors and is in collaboration with the companies

Enermet, Metso, Nanoway and JSP (Jyväskylä Science Park). New Nanoelectronics Education and Investment programme is going on during the years 2002-2004 in collaboration with several companies such as Enermet and Nokia. The programme is mainly funded by EU via the regional government and partly by companies. The programme allows improving the teaching in electronics and investments to equipment essential for research in nanoelectronics and nanotechnology.

The disordered materials group has continued its long-standing collaboration with companies dealing with paper machine technology and paper making. On the doctoral thesis level several projects were carried out during 2002.

The group participated in a research consortium funded jointly by TEKES and industry. The project included several Finnish research groups and was focussed on developing new experimental and numerical techniques for industrial multiphase flows. The main contribution of the JYFL group in the consortium was to develop a new device based on optical tomography for analyzing fibre suspension flows. Several other projects involved direct collaboration with industry. These projects included experiments, numerical simulations and modelling of processes such as measuring techniques for formation of paper, spreading of fluid droplet on paper surface, filtration of fibre suspension, and flow of polymer suspensions in pipes. In addition, direct numerical simulation was used in solving flow through samples of paper and paper-making fabrics with their pore structure resolved using high-resolution x-ray tomography. This novel method facilitates accurate prediction of various relevant transport and structural properties of materials like paper and fabrics. Modelling and numerical methods were also developed for analyzing the structure and rheological properties of wet paper webs. Industrial involvement in these projects included Metso Paper, Fortum, M-real, Tamfelt and KCL. Another area of application was development of novel methods and a related device using guided ultrasonic waves in assessing bone quality.

In addition to these postgraduate level projects, several Master's thesis projects were carried out on various aspects of the paper making processes. Work on diffusion and permeabilty of rock samples was continued in collaboration with Posiva. A completely new device was constructed for measuring the bulk volume of samples of any shape, based on applying the principle of acoustic Helmholtz resonance.

Education

http://www.phys.jyu.fi/teaching/index.html

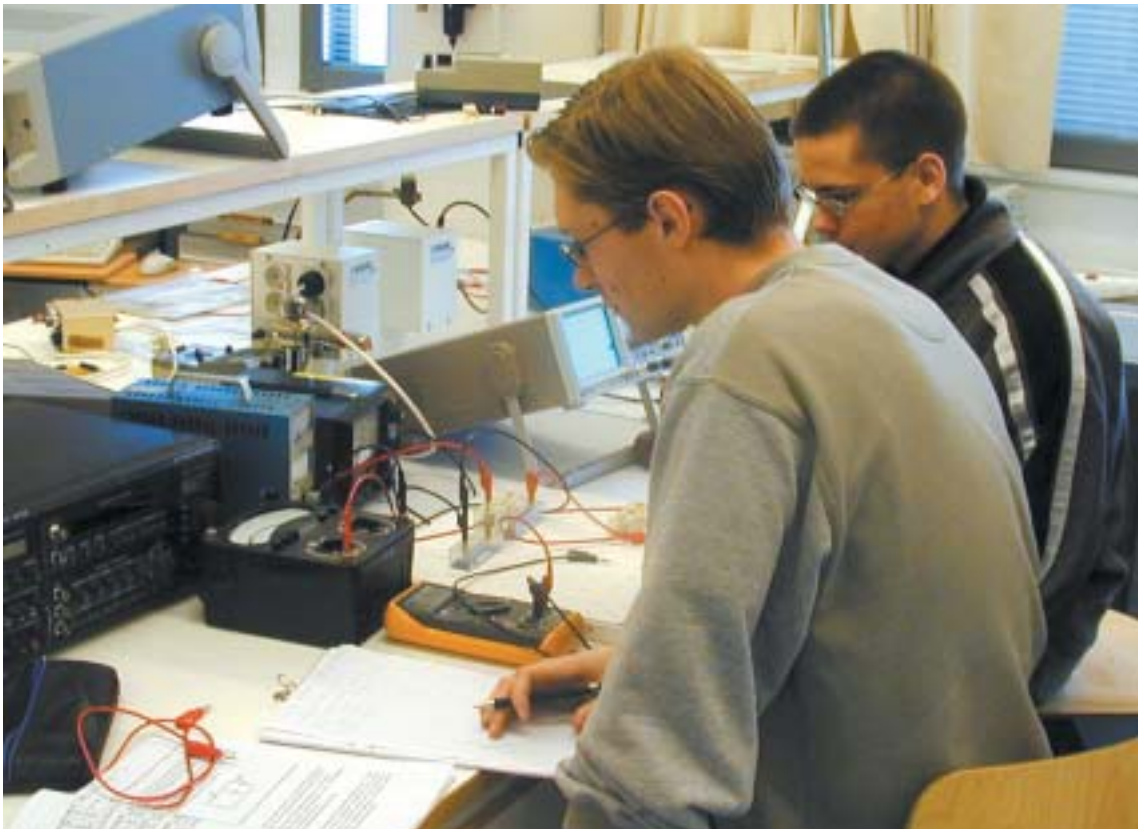
The Department of Physics offers a wide program of study in all academic levels. In 2002 about 500 undergraduates were working for a master degree, with physics, theoretical physics, applied physics, electronics, or physics teacher education as their specific major. In addition, some 30 students, mainly 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 2002 was 55. 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 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 12th time.

Student enrolment

In the summer 2002 there were 471 applicants for physics studies, with 294 indicating physics as their first choice. The entrance examination was organized together with 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 103 new students in autumn 2002. Additional 18 students from the autumn 2001 admission were enrolled in the beginning of the spring semester. About one quarter of the applicants and enrolled students were women.

Graduation

In 2002 32 students took their master degree in the Department. The number of degrees of Doctor of Philosophy was 5. These numbers show a downward fluctuation as compared with the record-breaking results of the pre-



vious year. The employment opportunities of the newly graduated students were 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 third 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 school teachers. About 20 teachers attended this course, which will be completed with one week's study period at CERN in 2003, to update their knowledge in nuclear, particle and nanophysics.

Development

At the undergraduate level the Department has developed the first-year course *Introduction to modern physics*, also called the '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 and each other, and learn to work together in small groups. Around 30 staff members have been involved in teaching and practical arrangements of the course.

Overall, the Department has devoted significant efforts to develop the teaching and to take it closer to the students. These include promoting team work 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 related developments have been very succesful, and its good effects include the reduction of the number of students quitting the studies. This program has been positively recognized by the Finnish Higher Education Evaluation Council, which recently nominated the Department of Physics as one of the high-quality education units in Finland.

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Ville Vauhkonen, Zeemanin ilmiön mittaamiseen tarkoitetun laitteiston erotuskyvyn määrittäminen ja optimointi

Auli Juntikka, Alkuaineiden syntyminen maailmankaikkeuteen

http://www.phys.jyu.fi/opetus/ (in Finnish)

Sippo Kurra, Termoakustinen Stirling-kone ja muut vastaavalla periaatteella toimivat lämpökoneet

Taina Pollari, Peruskoululaisten käsityksiä valosta

Teemu Nurmi, Lisääntyvään kokeellisuuteen yliopiston fysiikan opetuksessa luentodemonstraatioiden avulla

Tero Somppi, Peruskoululaisten käsityksiä arkipäivän fysiikasta

PhLic theses

Marko Oksanen, Sedimenttien PIXE-ajoitus
JYFL Laitosraportti 1/2002

PhD theses

Arto Nieminen, Manipulation of low-energy radioactive ion beams with an RFQ cooler; application to collinear laser spectroscopy
JYFL Research Report 1/2002

Mika Latva-Kokko, Statistical (physics) of rigidity and elasticity in randomly structured materials
JYFL Research Report 2/2002

Ilya Vadeiko, Dynamics and collective effects in cavity QED and in Bose-Einstein condensation
JYFL Research Report 3/2002

Tommi Alanko, Heavy ion stopping power measurements with transmission methods
JYFL Research Report 5/2002

Youbao Wang, Structure of doubly-even Pd and Cd nuclei studied by beta- decay
JYFL Research Report 6/2002

Degrees

(alphabetical order)

BSc degrees

Matti Hämäläinen (physics)
Jenni Kotila (physics)
Pekka Suominen (physics)
Olli Tarvainen (physics)
Minna Välitalo (physics)

MSc degrees

(main subject)
* = MSc includes teachers' pedagogical studies

Jouni Aavankari (physics)*
Tuomas Grahn (physics)
Birger Grönholm (physics)*
Jussi Haanpää (appl. physics)
Esko Hintikka (physics)*
Matti Hämäläinen (appl. physics)
Arto Javanainen (electronics)
Auli Juntikka (physics)*
Jami Kinnunen (theor. physics)
Sippo Kurra (physics)*
Jani Maaranen (appl. physics)
Lasse Miettinen (physics)
Sami Minkkinen (physics)*
Tuomas Mustonen (appl. physics)
Tom Nevanpää (physics)*
Petri Niemi (appl. physics)
Teemu Nurmi (physics)*
Jaana Ojala (appl. physics)
Henry Ojansivu (appl. physics)
Jukka Parkkinen (physics)*
Ari Peltola (theor. physics)
Sami Peltonen (physics)
Mika Pikkarainen (appl. physics)
Taina Pollari (physics)*
Kari Rytkönen (theor. physics)
Pekka Suominen (physics)
Janne Takanen (appl. physics)*
Olli Tarvainen (physics)
Pekka Timonen (theor. physics)
Sampo Tuukkanen (electronics)

Ville Vauhkonen (physics)*
Jussi Väisänen (electronics)

PhLic degrees

Marko Oksanen (appl. physics)

PhD degrees

Tommi Alanko (physics)
Mika Latva-Kokko (physics)
Arto Nieminen (physics)
Ilya Vadeiko (physics)
Youbao Wang (physics)

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