Estonian Higher Education Accreditation Center

evaluation of Estonian research in Physics

Institutes evaluated:

Laboratory of Chemical Physics

National Institute of Chemical Physics and Biophysics

Institute of Physics

Tallinn Technical University

Section of Physics

Department of Natural Sciences

Tallinn Pedagogical University

Chair of Field Theory

Institute of Theoretical Physics

University of Tartu

Institute of Experimental Physics and Technology, Faculty of Physics and Chemistry

University of Tartu

Institute of Physics

University of Tartu

Evaluation dates: May 27th to June 2nd 200l

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Part I

General overview

The evaluation team consisted of Prof. Christian Bohm (Stockholm University, Sweden), Prof. Sune Svanberg (Lund Institute of Technology, Sweden; team chairman), Prof. Anatoly Trukhin (University of Latvia, Riga, Latvia) and Prof. Igor Zoric (Chalmers University of Technology, Gothenburg, Sweden).

The evaluation was organized by the Estonian Higher Education Accreditation Center (EHEAC). The evaluation was carried out through an examination of documents and a series of site visits, interviews and consultations with the research staff and with students over the period May 27th - June 2nd, 2001. each evaluator had previously received self-assessment reports from the units to be evaluated:

Laboratory of Chemical Physics, National Institute of Chemical Physics and Biophysics (NICPB)

Institute of Physics, Tallinn Technical University (TTU)

Section of Physics, Department of Natural Sciences, Tallinn Pedagogical University (TPU)

Chair of Field Theory, Institute of Theoretical Physics, University of Tartu (TU)

Institute of Experimental Physics and Technology, Faculty of Physics and Chemistry, University of Tartu

Institute of Physics, University of Tartu (IP TU)

The evaluated institutes, laboratories, research groups and individual scientists provided additional material during the visit.

The visits to the institutes started with a general introduction of the institute organization, the financing and the main research topics given by the directors of each institute. The second phase consisted of topic-by-topic presentations of research activities by the team leaders. Finally, the evaluators visited laboratories and interacted with individual researchers.

The evaluators were asked to

1. Evaluate the quality of the research, the overall capacity of the research teams and the possibilities for application of research results in Estonia;
2. Identify deficiencies in the activities of research and development institutions;
3. Give recommendations on the development concerning research and development, and on research areas necessary to the State of Estonia.

The team was given the following material: working schedule, principles and criteria for the evaluation of research and development institutions, guidelines to the experts for the research evaluation, and self-evaluation reports as discussed above.

The team arrived on May 27, 2001 in Tallinn; was shortly briefed at the EHEAC and transferred to Tartu during the same evening. The team visited the Faculty of Physics and Chemistry, Institute of Experimental Physics and Technology, TU, and the Chair of Field Theory, Institute of Theoretical Physics, (TU) on May 28. on May 29 the team had its site visit to the Institute of Physics (TU) and returned to Tallinn in the evening.

On May 30 the evaluation concerned the Tallinn Pedagogical University, Department of Natural Sciences, Section of Physics and the Tallinn Technical University, Institute of Physics. Finally, on May 31 the team visited the Laboratory of Chemical Physics, National Institute of Chemical Physics and Biophysics.

On a first evaluation point, the *quality of the research activities* was considered. This assessment is largely based on the records of scientific publications. Regarding the grading of the research activities, the evaluation team was instructed by the EHEAC to reserve the term **excellent** for groups, which were found to be among the best 10% of the European groups in the corresponding field. Similarly, the term **excellent to good** should be used if the evaluated group was found to be among the best 25 % of corresponding European groups. The full scale comprised 7 levels, in addition to the highest ones the grades are **good, good to satisfactory, satisfactory, satisfactory to unsatisfactory,** and **unsatisfactory.**

The *over-all capability* of a research unit was evaluated based on a the combined assessment of the following criteria (each graded in three levels):

- The originality/novelity of past and ongoing research activities
- The strategy and perspective of the research
- Multidiciplinarity and relevance for other research areas
- The competence of the research groups and their capacity for development
- National and international co-operation
- Success in applying for grants

As the result of this assessment one of the four grades **excellent, good, satisfactory** or **unsatisfactory** was given for the group.

Finally, on a third evaluation point the implementation opportunities for the research results and their importance for the Estonian society was assessed. Here we adopted a three level grading: no comment, good or very good.

Part II

General Remarks

The evaluators found several examples of research in physics and related areas, which are on a high international level. However, some groups are showing elements of decline. One general problem is the risk for “brain drain” due to the lack of attractive perspectives for young scientists (the fact is that wages, even for established scientists, are still below the level of ordinary employees in commerce, banking, etc). The enthusiasm for a career in science cannot always compensate the above mentioned shortcomings. Another general problem is the age structure in some places that may lead to loss of valuable knowledge if senior scientists retire before a younger generation is fully trained.

The aim of this evaluation was twofold: a) to judge the quality of research and overall capability of research teams and b) to give recommendations on possible ways to improve the development of Estonian physics. Science is an important cultural endeavor, but in a shorter perspective its most important task is producing the knowledge, which is the basis for the modern education required to serve high-tech industries and for developing competitive applications that can eventually be turned into successful industrial products. When considering the balance between basic and applied research it is important to realize that good basic research is the source of successful applied research. The well functioning research institutes of Estonia are a valuable national resource that require substantial funding to survive and grow, but that gives Estonia an important edge in its economic development. Even though Estonia spends a similar percentage of the GNP on government funded research as the leading economies in Europe it may well be that one should exceed this level until industry funded research can gather momentum.

Estonian science (physics and chemistry) had already reached a high level during the Soviet times. Therefore it could take advantage of the new possibilities that arose after the disintegration of the Soviet Union. However, the contacts with industry were largely broken. The loss of industrial involvement was partly compensated by contacts with universities in foreign countries. Via them connections were established with their industry. But these contacts were more on the individual level than on an official level, reducing the benefit for the Estonian society. Unless otherwise agreed the innovations made by a visiting scientist belong to the host country, and are of little value for the native country.

The broken connections between scientific research and industry constitute a problem for Estonia. However, there are encouraging examples of a growing production of advanced scientific instrumentation (vacuum monochromators, lasers, cryostats etc) in Estonia. Strengthening the bonds between scientific and industrial communities must be high on the priority list. It is also important to encourage the local financial institutions to supply venture capital to existing high-tech companies and spin-off companies or to promote contacts with sources from other countries.

Estonian science has gone through profound changes after the disintegration of the Soviet Union and the regaining of independence. These changes had both positive and negative consequences. The fact that one managed to secure the scientific potential of the old research structure is clearly positive. On the opposite side we notice that a sole reliance on enthusiasm is not enough and many capable scientists, especially young persons with families, were pressed to leave science. In some places the research staff was drastically reduced leaving only the best merited scientists, which were often the oldest. There is now an influx of new scientists, but with a very skew age profile it has become important to transfer the knowledge fast. Creating emeritus positions for some of the best scientists would help to relieve the situation.

There are examples of inspiring scientific enthusiasm among leading physicists (Prof. E. Lippmaa, NICPB, Dr. A. Lõhmus, IP UT and others) which show the importance of the human element. Sometimes it is said that it is difficult to carry out advanced physics research in a small country like Estonia, but we found several examples at the NICPB and IP TU, which prove the opposite. The problem is to keep and develop the high-level standards. The two previous examples show the importance of the scientific environment and leadership.

The technological infrastructure varies among the visited institutions but is remarkable strong when it concerns computer usage and computer communication. The university institutions we visited were well equipped with personal computers and computer usage was well integrated into the teaching process. The computer maturity was high in the institutes such as NICSB and especially in IP TU. Computer based tools such as Internet, presentations, spreadsheets and word processing were well integrated into the daily activities.

Part III

Evaluation of Individual Institutes and Research Groups

Physics Department, Faculty of Physics and Chemistry, University of Tartu

The Faculty of Physics and Chemistry of the Tartu University is the overlaying organization for the Department of Physics. This department comprises institutes for Experimental Physics and Technology, Environmental Physics, Theoretical Physics and Materials Science. The present evaluation concerns two units at the Institute of Experimental Physics and Technology – the chairs of Applied Physics (Doc. K. Tarpea), and Optics and Spectroscopy (Prof. J. Aviksoo/Doc. M. Laan) and one unit at the Institute of Theoretical Physics – the chair of Field Theory (Prof. R. Tammelo).

There are very tight bonds between the Department of Physics and the Institute of Physics, University of Tartu. Thus, several of the senior members of the Institute of Physics fill chairs at the Department of Physics. They have mostly teaching duties at the Department while pursuing their research at the Institute. Because of this, the activities of the professors P. Saari, V. Hiznyakov and A. Lushchik will be evaluated in connection with the Institute of Physics. Under the present heading three experimental activities, gas discharge physics, biomedical engineering and medical physics, and dielectric and optical material physics will be discussed.

Optics and Spectroscopy

Gas Discharge Laboratory and Solid State Physics

Project leaders: Jaak Aaviksoo, Matti Laan

The main activity of this unit is in the field of gas discharge physics and applications. The Gas Discharge Laboratory is headed by M. Laan. The Solid State Physics activities are pursued mainly at the Institute of Physics. Moreover, with the team leader Prof. J. Aaviksoo serving as the Rector of Tartu University the activities in the latter field are now limited. Thus the present evaluation concerns the discharge physics. The group has a long experience in the field of gas discharge and plasma physics and played an important part within this field in Soviet physics and technology. Present fields of study include positive, negative and high frequency corona discharges, in particular the interaction with electronegative gases, and capillary discharges relevant in the quest for CW excimer laser action. Applications include excimer lasers and lamps, trace gas detection, electric field sensing and laser cleaning of surfaces. A newer aspect is the generation of nano-sized aerosol particles in the discharge.

The group maintains a high expertise in discharge physics, which has lead to several interesting technological possibilities. The attempts to achieve CW laser action in excimers are particularly intriguing. The equipment used by the group is mostly old. The plans to move towards plasma generation of nanoparticles and nanolayers are encouraged. The average age of the group staff is high and efforts to rejuvenate the group should be made.

The publishing records of the group are moderate. We find the research activities of this group to be **good** and the overall capability to be **good.** The implementation possibilities of the research in practical applications are very good.

Biomedical engineering and medical physics

Project leader: Arved Vain

The small group of A. Vain deals with biomechanical research and development, focusing on the function and characterization of skeletal muscles. This work has relevance to medical diagnostics, sports medicine and forensic sciences. The main technique used is to measure the muscular tone and elasticity with a handheld device, a myometer, developed by the group. The response of the muscle to a fast deformation is measured and physiological conditions are deduced from the position and acceleration data. The work is interdisciplinary with collaborators in physiology, rehabilitation medicine, oto-rhino-laryngology and psychiatry.

An important achievement of the group is the development of a useful instrument and its successful use in several applications. The technique is patented and has lead to industrial spin-off. Combined with the model for the skeletal muscle function developed, the measurement techniques should allow new diagnostic possibilities for skeletal muscles diseases.

The group is very small and the possibilities for a continuation of the physics-related work seem somewhat limited. The successful industrial spin-off activities will secure the availability of the instruments for clinical research. We consider the research activities as **good** and the overall capability of the research group as **good.** The implementation opportunities of the results are very good.

Synthesis and physical properties of wide band-gap dielectric and optical materials

Project leaders: K. Tarkpea and L. Pung

Two main objectives of this project are: a) to develop new functional dielectric materials, using atomic layer deposition techniques, that may eventually replace customary thermally produced SiO_2 in MOS technology and b) to understand the electronic structure of various defects and electronic relaxation processes in alkali earth sulfides. The highlights in the former case include the studies of halide and alkoxide precursors influence on the crystalization temperature, degree of ordering, electronic properties, etc in nm thick oxide films. In the latter case the studies of electronic structure of V centres and cation vacancies in neutron irradiated CaS constitute a notable example. The strength of the former activities lies in its strong contacts with the groups at the Institute of Physics TU and the University of Helsinki. To secure a stable long term development of this line of research it is necessary to introduce new experimental techiques, in addition to the existing one, that allow studies of the substrate/thin-film interface and the dielectric properties of thin films during the growth process. Another possibility involves implementation of the newly developed reflection spectrometry (developed at IP TU) to follow oxide growth kinetics. The combination of the latter techique with the quartz crystal microbalance method may lead to new and valuable insights into the early stage of the oxide growth process. In general, the strengthening of the “in house” experimental facilities is recommended. The publication record of K. Kukli (mostly done in collaboration with members of M. Leskelä´s group) is impressing.

The research activity is evaluated as **good** and the overall capability as **good**. The implementation opportunities for the research results are very good and highly relevant for the Estonian society.

Chair of field theory

Project leaders: Risto Tammelo, Rein Saar and Teet Örd

The chair of field theory was first filled in 1993, when Risto Tammelo was appointed professor, a position he has held since then. Together with the chair of astrophysics and the chair of statistical physics and quantum theory it forms the Department of theoretical physics. This is the only institution in Estonia that awards Ph.D. degrees in theoretical physics and has therefore an important mission to fill. There is a close collaboration with the Laboratory of theoretical physics of the Institute of Physics TU, both in teaching and research. The activity is spread over the following fields: field theory, general relativity, elementary particles and condensed systems. In field theory and general relativity it is interesting to find out under what conditions it is in principle possible to determine different entities related to the structure of space-time. One studies problems like, if and how a traveler who is on his way into a black hole can determine when his communication with the outside world will be cut off (passing the Schwarzschild radius). What mutual tidal forces do two freely falling bodies, with a relative velocity close the speed of light, experiences under different conditions? One also studies if and when one may carry out experiments to determine the existence of parallel universes. Combining quantum mechanics and general relativity one has studied methods to find approximate solutions to wave equations hoping that they may lead to experimentally verifiable conclusions. A generalization of the Dirac equation to cases with higher spins has eliminated previous difficulties and provided some results that may be checked against measurable data. In the area of high T_c superconductivity the study of the relation between structural transformations and superconductivity, based on models involving interband interactions, was carried out. Notable results include a calculation of the temperature dependence for two relaxation rates, within a two band model. The theoretical results agree with recent experimental observations. In the field of stochastic processes overdamped Brownian particles, moving in an asymmetric periodic potential and subjected to a superposition of both thermal and colored three-level noise, are studied. The central result of this work includes a prediction that at an appropriate temperature particle separation occurs in a system, characterized by different friction coefficients, and subjected to the above mentioned conditions.

The group is small now but if it at a later stage is merged with the theory group of the Institute of Physics one should reach a comfortable size. The research fields match each other well. The large number of students at the master level together with the age distribution of the full-time staff should warrant a favorable development of the group. We consider their research activities as **good** and the overall capability as **good**.

Institute of Physics, University of Tartu (IP TU)

EC Center of Excellence

The IP TU has, throughout its long and rich history, been and still is a center of excellence for physics research in Estonia. The photochemical spectral hole burning and hot luminescence are just two examples of phenomena discovered by the researchers at IP TU. The scientific staff of about 70 researchers is pursuing research in five basic areas.

These are: materials science, theory of the fundamental structure of matter, laser physics, biophysics, and environmental science. In 1997 the Institute was incorporated into the University of Tartu. 5-6 out of 9 physics professors at the TU do their research at the IP and teach courses at TU. Joining the IP is frequently the top priority for students pursuing graduate education in physics. The number of Current Contents referred papers, published by the IP TU staff and normalized per scientists, is about twice as large as the corresponding number for the next following research institute in Estonia. The funding of the IP TU activities is provided via the Ministry of Education, target financing of research activities, research grants from the ESF and EIF and via international R&D grants and contracts. A trademark of the IP TU is the flexibility of the research organization. Formally the research activities are centered in 13 laboratories but in practice a horizontal organization is in operation. The research teams are organized, by selecting the staff from different labs, to address the need of the target project for competent staff. Presently the IP TU staff is involved with 7 target financed projects. They are: memory materials and their laser spectroscopic studies, nanostructural materials, biophysical elementary processes and their dynamics, environmental radioactivity and radiation dose in Estonia, theory of the fundamental structure of matter, laser physics and laser optical technologies, and fundamental phenomena in dielectric materials and prospects of their application in technology.

Memory materials and their laser-spectroscopic studies

Project leader: Jaak Kikas

The main motivation of this project is a search for new materials to be used as memory elements. the basic physics behind this project theme involves high resolution solid-state optical spectroscopy, spectral hole burning and single-molecule spectroscopy. The main results include characteristics of spectral holes and hole-burning mechanisms in molecular crystals, glasses, proteins, local probing of solids by single-molecule spectroscopy, novel hole burning materials and mechanisms (n-irradiated diamonds, oxide layers and nanocrystalline systems). This research is funded from several ESF grants. Organic crystals, glasses and thin oxide films are main candidates as optical memory materials.

A significant infrastructure is built to realize this project. It includes sample preparation facilities (thin film growth, with different types of *in situ* control during the growth process) and tools for studies of their spectral-kinetic properties. The experimental data serve as a base for modeling of the fundamental behavior of the investigated materials. However, the realization of the main objective, i.e. the use of these materials as memory elements is still uncertain. Nevertheless, it is clear that the method of hole burning in molecular systems has a good perspective both for basic research and for creation of new memory elements.

The research activity is evaluated to be **excellent to good** and the overall capability of this team is **excellent**. the implementation opportunities are good.

Nanostructural materials

Project leader: Kristjan Haller

This is a large target project, centered at IP TU, involving 16 researchers (13 from IP TU and 3 from other institutions). It is one of the pillars of the Estonian efforts in the area of nanomaterial and nanotechnology R&D. Its main objective is to create a solid scientific and materials base for developing nanotechnology in Estonia. More specifically, it calls for developing preparation techniques for diverse nanostructural materials and studies of their structural, optical and electronic properties. The term “nanostructural” materials may involve few nm thick dielectric films, clusters of atoms or even individual atoms or molecules. Another objective of this project is the development of new experimental methods suitable for studies of nanostructural systems. The research team includes scientists with documented research experience in the area of atomic layer deposition technology, low temperature physics, laser spectroscopy, and condensed matter theory. A significant participation of younger scientists (grad/postgraduate students) is notable. The research team has at its disposal the infrastructure necessary for preparation and studies of physical properties of novel materials. The research highlights and results may be divided into the following categories: novel materials and their properties, new methods, and spin-off.

Novel materials and their properties

The relation between structural properties and preparation parameters (a choice of the precursor used in atomic layer deposition or substrate temperature) was established for a series of metal oxide films. The structure-dielectric properties relation for a series of atomic-layer chemical-vapour-deposition oxide films was examined. The spectral hole burning technique was applied on various nm size structures. The upconverted photoluminescence in semiconductor quantum dot structures was observed and explained. The dependence of the superconducting transition temperature on electric field and on the hole concentration has been calculated and found to be in good agreement with experimental results.

New methods

A. Lõhmus´ role in development work involving low temperature technology in combination with SPM is pivotal. The new devices, developed within this project, have a bright future and include: a device for combining AFM/STM with TEM, LHe dewars for single molecule spectroscopy (A. Lõhmus), novel sensors for CO and O_2 detection based on nm thick oxide films, and the development of incremental dielectric reflection method, by A. Rosental, R. Jaaniso and others, for studies of dielectric properties during the ALCVD growth process. In addition, within this project a central facility for thin film production using laser ablation is realised.

Spin-off

The development of an industrial and educational STM, by dr. A. Lõhmus and co-workers is remarkable. A commercial company, located in Sweden, takes care of marketing and sales of this device while the manufacturing base remains in Estonia.

The future prospects for the research team are bright. Focussing the activities on even thinner films (1-10 nm) and cluster based structures and studies of their structural and electronic properties are recommended. This will require the introduction of new methods needed to understand the preparation-structure-properties relation. In particular, as the film thickness is reduced, the need for studies of film-substrate interface phenomena becomes more important. A development of O_2 and CO sensors (prototypes) is also recommended. The research team should study possibilities for creating nanosize structures on diverse substrates and explore their physical and structural properties. The research team has a wide national and international co-operation network. The research activity is evaluated as **excellent to good** and the overall capability as **excellent**. The implementation opportunities for the research results are good/very good and highly relevant for the Estonian society.

Biophysical elementary processes and their dynamics

Project leader: Arvi Freiberg

The research group is pursuing a target-financed project in biophysical elementary processes employing temporally resolved ultrafast spectroscopy and hole-burning spectroscopy. This is a highly competitive field with many groups with excellent instrumentation active. The group was an early player in this field and helped organize the first international conference in ultrafast processes in Tallin in 1988, and again the 10^{th} conference in the series in 1997 in Tartu. The target financed project is one of the smaller at the IP TU with 5 researchers involved. The average age in the group is 50 and visiting PhD students and undergraduate students are involved in the activities.

Highlights during the evaluation period include the discovery, that excitons in bacterial antenna complexes dynamically localize within 100 fs to form a self-trapped exciton. The process increases the speed and efficiency of energy transfer in photosynthesis. Further, it was found that there is a high pressure-induced acceleration of primary photochemistry in the reaction centres of photosynthetic bacteria. Important insight in the early time evolution of transient spectra from LH2 antennas has also been obtained. The group benefits from the joint expertise in ultrafast and hole-burning spectroscopy and high-pressure techniques experience. The local equipment was initially of a very high international standard combining high temporal and spectral resolution in a unique way, but it is now old and collaboration with better equipped international partners is necessary and is widely utilized. The group has a very good publication record, is very active with invited talks at major conferences and is internationally well-known. It has a clear outlook for future directions including a strengthening of the interplay with theory.

The local activities of the group would benefit from adequate funds for upgrading its equipment to modern standards. We consider the research activities of the group as **excellent to good** and the overall capability of the group as **excellent.**

Environmental radioactivity and radiation dose in Estonia

Project leader: Enn Realo

This project consists of two parts. One part concerns the study of environmental radioactivity in Estonia and the other one concerns the development of nuclear spectrometric and modeling methods. The latter deals with quality assurance issues in connections with nuclear spectroscopy measurements of environmental samples, modeling the radionuclide pathways in nature and the interpretation of the phenomena arising in time-dependent nuclear resonant (Mössbauer) forward scattering of synchrotron radiation from randomly-oriented samples. The study of environmental radioactivity deals with the collection of data on radioactive waste deposits and on their radionuclide composition as well as the distribution of other radioactive substances in Estonia. Data from the investigations were compiled into international databases. The projects lead to the development of measurement equipment and different software packages.

The group has a competence that is unique for Estonia. It has a good international (especially Nordic) contact network and a reasonable age structure. The prospects for a favorable future development are good. We consider the research activities as **good** and the overall capability as **good**. The group provides important services to the Estonian society and it is possible that its activity may contribute to future products for the Estonian industry.

Theory of fundamental structure of matter

Project leader: V. Hizhnyakov

In terms of the team's size and scientific production this research group dominates strongly the Estonian scene in the area of theoretical condensed matter physics, optics and spectroscopy with some excursions in the area of general relativity and particle physics. The main topics in condensed matter theory include: decay of a local mode involving multiphonon processes, structural, magnetic and superconducting properties of strongly correlated systems and high T_c superconductors, theory of zero phonon lines, the relaxation of a collective and local excitations in matter etc. The research team is active in the development of new nonperturbative methods needed for the description of multiparticle emission in open quantum systems. In the field of high energy physics and gravitation the main results include development of higher-spin theory and applications of non-associative mechanism in quantum theory. A very strong interaction with experimentalists at the IP TU has resulted in several joint publications. The team leader is strongly involved in teaching of theoretical physics at the TU. Together with other team members he is also involved in the supervision of graduate students towards their M.Sc. and Ph.D. degrees. A sizable collaboration network is established involving Max Planck Institutes in Stuttgart and Dresden, Ulm University, TU Munchen, St Petersburg, Cornell University etc. About one third of the papers published in the period 1996-2000 are written with international collaboration. Several international cooperation grants have supported the travel and living costs for group members during their visits to partner institutions.

The research highlights are numerous. We shall exemplify the most important ones. The newly developed nonperturbative theory of multiparticle emission has been applied to studies of relaxation of strong vibrational modes in a quantum lattice, a process involving multiphonon emission. In addition, the same formalism was applied to studies of a stepwise quantum decay of vibrational solitons. The beautiful example of a collaborative effort between the IP TU theory team and experimentalists includes the work on the relaxation and hot luminescence of excitons in rare gas crystals. The asymmetric form and a sharp maximum in the relaxation peak as a function of vibrational quantum state, described by the theory, fits very well the observations of IP TU experimentalists (R. Kink et al.). The international recognition is confirmed by the selection of Prof. Hizhnyakov as one of the directors (A. Sievers from Cornell University is the other director) of the international workshop on “Nonlinear classical and quantum dynamics in solids” in Erice, Italy, 2003. In the area of strongly correlated systems the predicted order-disorder phase transition, caused by the change in doping level, was observed experimentally by M. Klein et al. The team has a good contingent of young graduate students and postdoctoral fellows and several capable researchers at intermediate positions. The scientific future for this team is excellent. The leadership, the intermediate researchers and the young scientists are there. We recommend an opening of the team activities in computational molecular and condensed matter physics. The model systems are useful for understanding the physics but with more precise experiments the need for realistic intramolecular and interatomic potentials arises and an effort in this direction is needed. In particular this becomes even more relevant if molecular dynamics studies of molecular and solid state processes are to be opened. More aggressive submission of research results in journals with high impact factor is also recommended.

The research team is evaluated as **excellent to good** and the overall capability as **excellent.**

Laser physics and laser-optical technologies

Project leader: Peeter Saari Co-leaders: Rein Kink and Aleksei Treshchalov

This target project involves 13 researchers from the laboratories of Low Temperatures, Crystal Spectroscopy and Laser Techniques. The project contains a rather diverse collection of projects reflecting the different interests of the three project leaders. Three solid-state projects concern: nonlinear dynamics of self-trapped excitons in rare-gas crystals, dynamics of exciton interaction with charge carriers in semiconductor crystals and electron transport properties in low-dimensional systems. Two projects relate to the study of localized electromagnetic waves – their theoretical description and experimental generation, and the non-linear interactions of such fields. Finally, two technological projects deal with the study of the physical processes in discharge-pumped excimer lasers and the development of lasers for medical applications.

As a whole the publication record of the group is good although uneven. The collaboration within Estonia mostly concerns industrial and medical aspects of lasers. International interaction is strong, particularly involving synchrotron radiation utilizing the Lund University.

Several solid state projects concerning electronic properties of materials are pursued:

a) Non-linear dynamics of self-trapped excitons in rare-gas crystals.

The luminescence of cryocrystals is investigated experimentally and theoretically. The observed hot luminescence of excitons in rare-gas crystals was explained in terms of the new non-perturbative relaxation theory proposed by V. Hizhnyakov, and developed within the target-financed project "Theory of the fundamental structure of the matter". The good agreement between the experimental and theoretical data was obtained. A wide national and international cooperation is established.

b) Dynamics of exciton interaction with charge carriers in semiconductor crystals

This small project concerns the study of the interaction between excitons and laser-induced free carriers in GaAs using time-resolved dual-channel modulated luminescence. The main achievement of the group is in the understanding of the physical processes in GaAs/AlAs superlattices.

c) Electron transport properties of low-dimensional systems.

The project is related to investigations of novel materials such as thin two-dimensional tungsten films and Ta_4Te_4Si quasi-one-dimensional nano- and micro-scale fibers at cryogenic temperatures. these materials have a potential for use as sensors in cryogenic particle detectors. Low-temperature magnetoresistance measurements were performed. Such data are well described by the established theory of electron-electron interaction in disordered metals. Future applications of this compound in nanoscale electronic devices could be envisaged.

An integrated theoretical and experimental effort in localized wave physics is pursued within the project. Such waves feature the inhibition of lateral and temporal spreading and are of great interest in e.g. optical communication, metrology, imaging and ultrafast spectroscopy. As a highlight, the experimental generation of so-called optical Bessel-X waves was demonstrated by the group. Further realistic optical schemes for the generation of localized waves have been proposed. The non-linear interaction of Bessel beams was also studied, demonstrating new features and indicating novel ways to control the non-linear response.

A successful program of laser development based on thorough physical studies is pursued by the group. Thus, efficient high-repetition rate excimer lasers have been developed with quasi sealed-off technology in a fruitful cooperation with Estonian laser industry. In a similar way, a very compact and user-friendly copper-vapour laser has been developed for dermatological applications. This is now in clinical use in Estonia and Finland.

The evaluated projects within the group are very diverse but each has strong merits. The solid-state projects are very productive, the localized wave physics is very original and innovative and the laser technology projects highly industrially relevant. As an over-all assessment we consider the research activities to be **excellent to good** and the overall capability of the research group to be **excellent.** Further, through its industrial/medical aspects the implementation opportunities and the relevance to the Estonian society are judged to be very good.

Fundamental phenomena in dielectric materials and prospects of their application in technology

Project leader: Aleksandr Lushchik.

The project is realized in the Laboratory of physics of ionic crystals (15 researchers) and in the Laboratory of X-ray spectroscopy (4 researchers) of the IP TU. The main objective of this project is to study creation, relaxation, decay and transfer of electronic excitations in wide gap materials like metal oxides or metal halides. Another objective is to use the obtained results for improvements of light sources, radiation detectors and memory materials relying on the use of luminescent materials with quantum yield higher than one. That latter situation is realized in the case of electronic excitation multiplication, i.e. a transformation of a non-elementary excitation to several elementary excitations. The wide band gap materials constitute an excellent playground for fundamental studies of these processes. This research is funded via several grants of the Estonian Science Foundation. experimental equipment for crystal growth and spectral-kinetic studies, in a wide spectral range -including the VUV region, is available at IP TU. The project is realized in cooperation with many organizations in Estonia and other countries including the use of the Lund University MAX-Lab and the HASYLAB experimental facilities in Hamburg.

highlights of basic research include observations of self-shrunk, self-trapped exciton in metal oxides, multiplication of electronic excitations in wide gap crystals and nanodimensional groups of spatially correlated electronic excitations in Ag doped alkali halides. The applied R&D include the development of new solid-state detectors based on fast temperature-stable emissions, new spectral transformers with quantum yield above unity for gas discharge devices, luminescent lamps etc.

The future prospects for this team are good. In the area of basic science a more detailed comparison of experimentally proposed models of self-shrunk excitons with quantum mechanical calculations is desired. In the area of applied research further improvements in the quality of grown crystals are suggested.

The research activity is evaluated **excellent to good** and the overall capability of the team is **excellent**. the implementation opportunities are very good.

Physics Section, Department of Natural Sciences, Pedagogical University (TPU)

The Physics Section of the Department of Natural Sciences, Pedagogical University of Tallinn has existed since 1991 when it was created from the former Tallinn Pedagogical Institute. The section has had research activities in general relativity, diffusion processes and didactics, but is now focussed on creating new research directions that better relate to the needs of TPU. The two research themes chosen were: stochastic processes in open systems and didactic problems of teaching physics in the conditions of educational reforms in Estonia. The first theme is an active area of physics with interesting new developments and it is an area, which is of large interest for other disciplines inside as well as outside the realm of natural science. One natural collaboration partner is the TPU Section of Geoecology. Other potential collaboration partners can be found in mathematics and economics. The other theme is an important and natural interest for a physics institute in a pedagogical university. It is a field that is of great importance for the future development of the educational system of Estonia.

Stochastic processes in open systems

Project leader: Romi Mankin

The theoretical part of this project is concentrated on studies of noise-driven processes. Examples include phase transitions induced by non-equilibrium fluctuations and appearance of directional motion in damped systems driven by asymmetric periodic potential and colored noise. The former model represents a possible mathematical description of some ecological and population processes while the latter leads to a phase separation in a system of Brownian particles with different friction coefficients. In addition, the issue of wave propagation (gravitational or electromagnetic) in an non-homogeneous environment (strongly varying gravitational field) has been analyzed. The main results are summarized in three recent Phys. Rev. E publications. This is a good achievement considering the teaching load of the authors. The weakness of this project lies in its concentration on mathematical descriptions. The connection to realistic relevant physical processes is not yet established. This panel recommends the concentration of all activities on noise-driven processes of relevance for biology, population science, marine ecology, etc. In addition a larger interplay of experiment and theory has to be established. We recommend the establishment of collaboration with experimental groups, generating data, relevant for this project (within Estonia and outside of the country). In addition we also suggest that many of the future M.Sc. students should be guided towards the area of stochastic processes.

The second part of this project is of experimental nature but with no overlap to the theoretical part. This activity, led by Ü. Ugaste, deals with macroscopic studies of diffusion processes in metallic binary systems, defect diffusion during Si oxidation and diffusion of light elements in materials subject to the radiation from thermonuclear plasmas. The articles are published mostly in journals outside of the physics mainstream and rely on a macroscopic approach for description of diffusion processes.

This research activity is evaluated as **good** and the overall capability as **good.** The application possibilities for the research results are good.

Didactics problems of teaching physics in the conditions of educational reforms in Estonia

Project leader: Ülo Ugaste

This project team, based in the Section of Physics, Tallinn Pedagogical University, consists of 6 members. Its main objectives include: modernization of physics curricula for secondary schools in Estonia, preparation and management of the state examinations in physics, writing of textbook for elementary and secondary schools, compilation and modernization of teaching aids for university physics, applications of IT in the teaching process, etc. In view of the recent changes in Estonian society these activities are necessary and important. The most important result of this project is a series of textbooks and teaching aids (>20) produced for Estonian schools, reflecting both the changes in the physics curricula and containing new teaching methodology. The content and the methodology presented in a series of three physics textbooks (Ü. Ugaste and coworkers) for high-school students are similar to textbooks at this level. In addition, two textbooks at the university level, aimed at teacher training students, are produced. Furthermore, R. Mankin is a co-author of a two-volume textbook on *"Statistical thermodynamics of non-equilibrium processes I+II*" for university physics majors. In the opinion of this panel this team is performing very well in this area. In the area of methodology we recommend the team to explore the possibilities of introducing additional learning methodologies (see the work of E. Mazur, U. of Maryland Physics Education Research Team, etc). The physics education of future teachers is important. Equally important is the ability of future physics teachers to convey the essence of scientific methods and approach to their students. For this reason the education of future teachers must include active researchers. The research base at the Section for Physics has to expand. The most efficient way includes fresh young blood backed by appropriate funding with a reasonable share of teaching duties.

This team´s activity is evaluated as **good** and the overall capability of the team as **good.** The results of this work are very relevant for the Estonian society. The future generations of Estonian elementary and high school students will use these textbooks for learning physics.

Institute of Physics, Tallinn Technical University (TTU)

The Institute of Physics of the Tallinn Technical University contains a chair of theoretical physics and one of experimental physics. It also contains the Tallinn observatory and the Tallinn gravimetry station. However, the current evaluation only concerns the first two. There are six different physics areas where research has been initiated: field theory, semiconductor physics, solid-state physics, stochastic processes, storage elements physical optics and x-ray diffraction. Apart from teaching physics courses for all engineering students, the department has opened an engineering physics branch with about 25 students admitted each year. It also has a graduate program with Ph.D. and master students.

Higher spin fields and superfields

Project leader: R.-K. Loide

This project is a collaboration project with the Institute of theoretical physics in Tartu and was introduced in that section. The TTU group is very small (one person). We consider the groups research activity as **good to satisfactory**, and the overall capability as **satisfactory**.

Electrical and optical properties of solid state materials

Project leader: Tõnu Ruus.

The small group of T. Ruus performs theoretical investigations of high temperature superconductors and experimental investigations of CdTe, $CuInSe_2$, as well as investigations of sodalite ceramics. They use luminescence and electric methods including Hall effect measurement. The theoretical investigations performed by M. Klopov in cooperation with N. Kristoffel (IP TU) are on a good level and his research activity would have been considered good if the productivity had been better. Overall we consider the group research activity slightly below **satisfactory**, and the overall capability as **satisfactory**.

The National Institute of Chemical Physics and Biophysics (NICPB)

Laboratory of chemical physics

NICPB was established in 1980, under the patronage of the Estonian Academy of Sciences with a dynamic and visionary leader (E. Lippmaa). It has a special status within the Estonian research community. It is the only national institute, which reports directly to the parliament. The NICPB is totally independent in its research activities. The evaluation team met E. Lippmaa, the Chairman of the Scientific council, and got a first hand information about the plans and visions in the area of chemical physics. The evaluation team visited only the Laboratory of Chemical Physics of the NICPB. This evaluation does not deal with the remaining activities within the institute. Since this was the last leg of a four-day visit to all physics/chemical physics research groups in Estonia, it was easy to establish that the research staff at the NICPB has access to the best equipment and support facilities in the country in the field of NMR, low temperature physics and modern analytical mass spectrometry. The Laboratory of chemical physics has its research activities in the fields of high-resolution solid state NMR, low temperature physics, applied quantum mechanics and quantum computation, analytical mass spectrometry and NMR chemical shift studies. A strong multidisciplinary approach is removing what otherwise may be sharp barriers. The NMR researchers dealing with high resolution spectroscopy of zeolite based materials are enjoying synergetic effects from the work done by quantum chemists dealing with *ab initio* quantum chemistry based calculations on the same systems. The latter group belongs formally to another research lab. The barriers for cooperation within the NICPB and with international partners have low "activation energies". The staff is young (35 is the average age). Notable is the absence of graduate students from Tallinn and Tartu based universities. The general philosophy has been to pursue the excellence not the breadth/growth. The Laboratory of chemical physics has a very strong collaboration program with many leading research groups in the field of chemical physics. This has resulted in a considerable number of joint publications with international partners (University of Illinois at Urbana, USA, with its strong research program in NMR and high T_c systems is one example). In addition to the obvious benefits the strong collaboration program may also cause problems. Some of the most talented researchers do, for one reason or the other, most of their work at partner sites and/or stay there for long periods. In the long run this may deplete the NICPB of its talent.

Solid state NMR

Project leader: Ago Samoson

This project deals with technical development of new techniques in solid-state NMR spectroscopy and in NMR- and NQR studies of zeolites and high-T_c superconductors. The work is carried out in a close collaboration with many laboratories in Switzerland, Germany, Japan and the USA, including the world´s leading magnet laboratory, NHMFL in Tallahassee. The NICPB laboratory has long been a leading player in the field of NMR techniques, and this tradition continues. Thus, the double angle rotation NMR technique has been strongly refined using improved designs allowing substantially increased rotation rates as compared to previously and rotors have been diminished in size for small sample volume applications. Automated long- time data collection has been achieved. The group also realized that a combination of the double axis rotation and the multi-quantum NMR technique gives a qualitative strong improvement yielding both chemical shifts as well as the quadrupole interaction parameters for every atomic site.

Studies of 17O NMR signals from isotope enriched samples have been performed extensively for zeolites as well as superconductors. Corresponding theoretical developments have been performed in collaborations.

The publication record of the group is impressive. The age distribution is satisfactory with several young and energetic collaborators. We consider the research activities of the group to be **good to excellent** and its over-all capacity as **excellent.**

Low temperature physics

Project leader: Toomas Rõõm

The research in low temperature physics at the NICPB is mainly concerned with understanding the physics of high temperature superconductivity, low dimensional spin systems and development of new particle detectors based on superconducting bolometers. The research team is small (5 scientists+PI) with an impressive number of publications in high impact factor journals (PRL, Science). G. Blumberg is a young (32) researcher with a most impressive publication record. Some research highlights in the area of strongly correlated systems and high T_c superconductivity include Raman studies of lattice and spin dynamics in $La_{2/3}$ $Sr_{1/3}NiO_4$ near the charge and spin ordering transition and Raman studies of electronic excitations across the superconducting energy gap in an overdoped $Tl_2Ba_2CuO_{6+d}$ in a high magnetic field. In the former case spin and charge ordering in a commensurately doped Mott-Hubbard systems was investigated in the stripe phase. The experimental observations revealed formation of superlattice, pseudogap opening in the e-h excitation spectra and two types of spin excitations below the charge ordering transition. The observed temperature dependence suggests that the charge ordering drives the spin ordering in the system. In the latter case an unusual variation of the superconducting condensate density with external magnetic field was observed. The latter effect is associated with the renormalization of the quasiparticle spectra in the vicinity of Abrikosov vortex lines in the mixed state in real space. Another interesting work concerns the studies of the physics of ordering phenomena of CuO_2 planes in the La-Sr-Cu-O family of superconductors. The work on low dimensional spin systems required the development of far infrared spectrometry (1-100 cm^{-1} range) at low temperatures in high magnetic fields for studies of magnetic excitations in spin systems with restricted dimensionality. This is a very powerful and elegant method for this type of studies. The team's work on particle detectors, involving superconducting thin films stabilized in the middle of the superconduction transition, is promising. The selection of research topics, the quality of researchers, the existing infrastructure and the available funding promise a successful future. In addition to the work on strongly correlated systems and high T_c materials, the search for low-dimensional model systems involving clusters of a few dozen coupled spins/cluster opens ways for new and rich physics. The only problem the evaluation team sees is the fact that most of the work done by some team members (GB, RS, ..) was done at partner laboratories. To some extent this is caused by the availability of high quality samples at partner locations. There are certainly many other local factors influencing this pattern. A process of bringing "home" the most talented people should be initiated at an early stage via a proper induction method (a combination of a reasonable salary and a favorable research environment etc.). A lack of graduate students is also notable. The research activity is evaluated as **excellent to good** and the overall capability as **excellent.** The implementation opportunities for the research results are good/very good.

Theoretical and computational physics

Project leaders: Martti Raidal and Endel Lippmaa

This small group has a wide area of research. The main areas are particle field theory and quantum computing, two areas in rapid development. Topics of special interest in particle physics of today are explaining the mass of neutrinos, the existence of the predicted Higgs particle, and the existence of supersymmetry.

A number of experimental results that indicate that neutrinos have small non-zero masses have been reported in recent years. It is of great interest to find possible explanations to these results.

The so far extremely successful Standard Model combining the electromagnetic and the weak force also predicts the existence of a new particle, the Higgs particle, which is required to explain why most particles have mass. However, one does not know if there is only one Higgs particle or if there are several and what are their masses.

We know that all particles belong to one of two categories, bosons or fermions. Supersymmetry says that all particles have a partner of the opposite type but with a different mass and with other properties different as well, greatly increasing the total number of particles.

Results relevant to the latter two topics have started to arrive and will certainly appear once the new large LHC accelerator is put into operation at CERN five years from now. The research fields of the NICPB theoretical and computational physics group touch all three topics mentioned above. One paper relates the results from measurements of the muon anomalous magnetic moment and the neutrino mass to the rates of other measurable processes. Another paper combines string theory, which tells us that the universe consists of our four dimensions and seven other small, hidden dimensions, with the Standard Model to explain why the neutrino mass is so small. Here one assumes that the extra dimensions are not as small as otherwise assumed. This model predicts three different types of Higgs particles. The group has also been involved in the design of the large CMS detector at CERN looking for solutions to how one can use gas detectors in the central tracking subdetector. It was also a leading partner in the preparation of a proposal for a possible new detector at the LHC accelerator at CERN.

The quantum computer activity is a challenging endeavor. The group has been conducting theoretical feasibility studies. There is now an open competition for the first practically useful scheme. The coupled NMR spin approach is one of the serious contenders. NICPBs experience in NMR physics, NMR materials and in developing NMR instrumentation promises important contributions to the field.

The group, especially M. Raidal, has had an impressive productivity. Its participation at CERN helps to make Estonia visible in the field of “big science”. Being associated with CERN provides access to the tools and results, physics as well as technological, of the particle physics community. We consider the research activities as **excellent to good** and the overall capability as **good**. The latter rating reflects our opinion that we find it extremely important that the group is strengthened with new members to reduce its vulnerability. The CERN connections may be of interest for Estonian industry and the possibility to send technology fellows may help to bring back valuable experiences.

Mass spectrometry

Project leaders: Juhan Subbi, Rein Pikver

Mass spectrometry is a powerful technique in analytical chemistry. With the development of Matrix Assisted Laser Desorption Ionization (MALDI) a very powerful technique has become available for the analysis of large biological molecules. During the last 10 years this technique and the Electrospray Ionization (ESI) alternative have revolutionized analytical biochemistry. The NICPB has been part of this revolution and is presently using the MALDI technique extensively. Two spectrometers using the Time-Of-Flight (TOF) technique were devoloped employing advanced design software. The deep understanding of the technology allowed the group to further develop and apply the technique for demanding applications. A further MALDI system employs an Ion Cyclotron Resonance (ICR) mass spectrometer using a superconducting magnet, a new ion-trap design and Fourier transform free-induction decay read out. The equipment developed is of great importance for the in-house and collaborative biophysics/biochemistry work including proteomics.

It is very clear that the group is very competent and innovative and is an important asset for the Estonian modern biochemistry community and also for many other Estonian groups. It also opened the door to collaboration with many high-level foreign partners. The field is highly competitive with powerful industrial players on the scene, which makes it difficult for a small group to keep the lead. With advanced commercial instruments available on the market, the competitive advantage of the NICPB group is its flexibility to adopt its equipment to specific needs based on its deep technological insight.

We judge the research activities as **good** and the averall capability of the group as **excellent.** The implementation opportunities and importance for the Estonian society are very good.

The project “NMR chemical shifts” (Project leader: Tõnis Pehk) is not evaluated here since it concerns chemistry and was recently evaluated within that context.

Part IV

Recommendations

- The IP TU has to modernize the experimental equipment, otherwise the old equipment will become the bottleneck for further development in the international arena.
- A plan for strengthening of the research base at the Dept. of Physics, Tallinn Technical University is needed. TTU is a prime engineering school in the country and the credibility of this section shall remain doubtful until this remedy is taken.
- Section of Physics of Tallinn Pedagogical University needs improved economic and research stability. Fluctuations in an already small number of admitted students (15 per year) have dramatic consequences for the section. The improvement may take place by increasing the number of available places and by creating a stable research environment. The latter includes the hiring of additional collaborators that can compete for funding.
- Most of the equipment at the Dept. of Physics and Applied Physics, University of Tartu is old and has to be modernized if continued internationally competitive research is to be carried out.
- A homogeneous system has to be created that will allow the use of the expertise and knowledge of skillful older researchers to be transferred smoothly to the younger generation without losses for science. At present the solution exists for retired professors only. The creation of permanent tenure positions with improvement of wages for experienced senior researchers would generate a higher social status for scientists. It would also make hard core science more attractive as a career choice for younger people.

Conclusions

Physics of a high international standard is being pursued in Estonia. Much of the excellence found relates to the extensive activities at the two independent research institutes evaluated, the Institute of Physics, University of Tartu, and the National Institute of Chemical Physics and Biophysics in Tallinn. Both have a strong and dynamic leadership and the critical mass and cohesion to provide a stimulating scientific atmosphere. These institutions should be considered as extremely valuable national assets in the dynamical development of Estonia, and efforts should be made to ensure their vitality.

The research found at the more traditional departments of the universities is partly of a good quality, but the research environments were generally found to be rather weak. This may be due to lack of resources but is probably also an issue of leadership. With direct access to the students, inspiring projects should be easy to man. The activities evaluated at the two Tallinn universities are small and not very significant. The committee welcomes the initiative at the Tallinn Pedagogical University to focus on the theme of stochastics, which is judged to have a good potential.

Physics research at the Tallinn Technical University needs to be vitalized given its importance for the engineering education.