

ENGINEERING PHYSICS AND MATHEMATICS

SCIENCE FOR TOMORROW'S TECHNOLOGY



HELSINKI UNIVERSITY OF TECHNOLOGY TKK

Department of Engineering Physics
and Mathematics

BACKGROUND IN NEW APPLICATIONS



The old University of Technology by the Hietalahti square in the 1930's

—through solid basics towards a brilliant future

The roots of teaching Engineering Physics go back to the 1940's. As the structure of Finnish industry changed after the Second World War, a need arose for masters of science in technology with a strong education in mathematics and physics. Professor Erkki Laurila constructed a degree programme with modern subjects, such as electronics, automation and physical instrumentation.



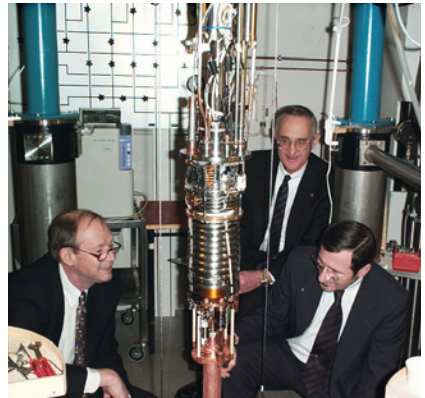
The adoption of nuclear power became topical in the 1950's, and Professor Pekka Jauho was hired to develop education and research in the field. Professor Teuvo Kohonen moved in the 1960's through electronics and computer science over to information science.

The constructors of the nuclear reactor simulator (from left) Aulis Hellsten, Teuvo Kohonen and Raimo Tuuli testing the device in the basement laboratory of the old University of Technology in January 1957

Professor Olli Lounasmaa founded the Low Temperature Laboratory in the 1960's. He introduced the Anglo-Saxon tradition of teamwork to research, and in particular, created the spirit that also Finnish science can reach the cutting-edge. Professors Laurila, Jauho, Kohonen and Lounasmaa were all appointed members of academy.

The use of computers for numerical calculations in the 1960's caused the need to launch, alongside with engineering physics, a programme for mathematics engineers. This started a strong tradition in numerical analysis and systems sciences. Systems sciences also brought connections to the teaching of economics and business.

Renewal from inside and spawning new branches of science and technology have always been characteristics of the former Department of Engineering Physics and the current Department of Engineering Physics and Mathematics. For instance, automation, electronics and information sciences have become their own departments in TKK.



Low temperature laboratory. The 1996 physics nobelists Bob Richardson, David Lee and Douglas Osheroff admire the intricate details of the YKI cryostat which has obtained record low temperatures when measuring nuclear magnetic ordering in copper, silver, rhodium and lithium.

TKK's main building, designed by Alvar Aalto, has been a central landmark already for half a century. The Institute of Mathematics, the Laboratory of Physics and the Systems Analysis Laboratory are units of the Department of Engineering Physics and Mathematics presently located in the main building.



The Department of Engineering Physics and Mathematics aims to:

- create new areas of high technology in Finland
- be an important resource for high-tech industry
- produce high level experts, influencers and scientists.





TOWARDS THE DOCTORATE

The department's success is made up of talented students, outstanding personnel, high level research and researcher training, excellent teaching, proximity of mathematics and physics in the same department and efficient international networking.

The high level and reputation of the education have ensured a high ranking in student admissions. Its character of a research and researcher training unit is portrayed by the students' eagerness to earn a doctoral degree. Presently one quarter of the students continue their studies after their master's degree to the doctorate. The objective is that every second student would get a doctoral degree.

Four national graduate schools are coordinated by the units of the Department of Engineering Physics and Mathematics. The department's units also run one of the national centres of excellence in research appointed by the Academy of Finland, and participate actively in another three.



Networking for multidisciplinary

The department's quality and multidisciplinary nature are promoted through networking. Major subjects which involve several branches of engineering science, such as biomedical engineering, advanced energy systems, nanotechnology and optics, have been started in collaboration with other departments (Mechanical Engineering, Electrical and Communications Engineering, Chemical Engineering).

Important collaborators outside TKK include the University of Helsinki, the BioMag research centre, Helsinki Institute of Physics, the Rolf Nevanlinna Institute, the State Technical Research Centre VTT and CSC Scientific Computing Ltd.

The Low Temperature Laboratory and the Laboratory of Computer and Information Science, which host centres of excellence outside the department, are eager to recruit their researchers among students of engineering physics and mathematics.

International activity is visible in the research of the department. Research projects are mainly carried out in international collaboration and almost half of post-doc researchers have come from abroad. The department recruits foreign students at B.Sc. and M.Sc. levels to study for a doctoral degree.



Physics Nobelists of 1997 Steven Chu and William Phillips visiting TKK's laser laboratory

Engineering physics and mathematics

A degree programme worth competing for



The teaching of engineering physics and mathematics is based on giving a firm foundation in physics, mathematics and computing to highly qualified students, who learn to apply this knowledge and these skills in various branches of science and technology.

Graduates of the department have a generic education that enables them to work in many areas of technology and adapt to quick changes in the operating environment.

In accordance with the Bologna agreement, the lower degree programme of engineering physics and mathematics

leads to the degree of bachelor of science in technology, which is intended as an intermediate step. The upper programme leads to the degree of master of science in technology.

There are four possible major subjects for the bachelor's degree: engineering physics, mathematics, mechanics and systems sciences.

A master's degree in engineering physics can have a major subject of engineering physics, optics, nanotechnology, advanced energy systems or biomedical engineering.

Mathematics-based major subjects for the master's degree are mathematics and mechanics. Systems sciences lead to the major of systems and operations research.

The teaching given by the department is highly appreciated. Engineering physics and mathematics has been selected a centre of excellence in teaching during 1997–1998 and a unit of high quality education during 1999–2004.

Bachelor's degree

Basic studies in mathematics and physics

The courses of mathematics provide basic knowledge of mathematical tools that are necessary in all branches of engineering. These courses teach the most important properties of solutions of the most common equations.

The courses of physics explore the basics of classical and modern physics. Laboratory courses give an introduction to the world of physical phenomena through performing empirical measurements and reporting about them.

Engineering physics

The major subject courses expand and extend the knowledge acquired from basic courses. They give a solid foundation of important areas of physics, such as quantum mechanics, thermodynamics and statistical physics, electrodynamics, materials physics, and nuclear and elementary particle physics. The education of a professional physicist in the upper degree programme is built on this foundation.

Mathematics

The major subject courses extend the knowledge of modern mathematics and functional analysis acquired from basic courses. Basics of optimization and stochastics and the theory of function spaces and partial differential equations are also studied.

Mechanics

The major subject courses create a firm basis for theoretical particle and continuum mechanics.

Systems sciences

The major subject is aimed at providing basic skills for constructing models and using them in decision making and in the analysis, design and optimization of large, mainly techno-economic systems.

Computational science and engineering

An interdisciplinary minor subject designed to support the use of mathematical models in the research of complex phenomena in various areas, and in the analysis aiming at exploiting these phenomena.

Discrete mathematics

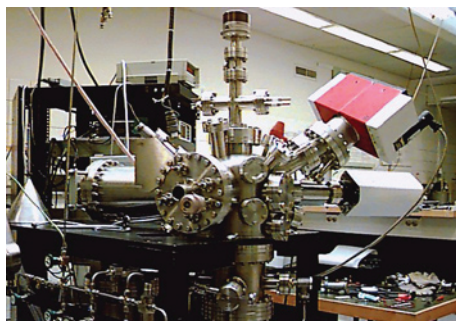
Minor subject for B.Sc. and M.Sc. degrees. Noncontinuous and algorithmic reasoning in computer science, communication theory, optimization and mathematics.

Master's degree

Major subjects of the master's degree

Engineering physics	Mathematics
Semiconductors, polymers Nanophysics and nanomaterials Positron physics, surface science Theoretical and computational physics Quantum mechanics and quantum computing Nonequilibrium phenomena and physical optimization Modelling of biological phenomena	Mathematical analysis Linear algebra, scientific computing Partial differential equations Inverse problems, imaging Iterations and complex dynamics Stochastics, risk management FEM models and numerical analysis
Engineering physics may include some parts of Optics, Nanotechnology, Advanced energy systems and Biomedical engineering, or they may be chosen as independent majors.	Mechanics
	Continuum mechanics Modelling of structures and materials Computational fluid dynamics
Optics	Systems and operations research
Laser physics and quantum optics Photonics and nano-optics	Optimization, decision analysis, game theory Investment theory Risk and technology assessment Energy and environmental systems Applied philosophy and system intelligence
Nanotechnology	Computational science and engineering
Molecular materials Nanostructures and nanotubes	Minor subject for B.Sc. and M.Sc. degrees. Produces new scientific knowledge by computational means. Uses mathematical models, simulations and visualization.
Advanced energy systems	Discrete mathematics
Fusion energy, plasma physics Nuclear engineering, radiation physics New energy technologies, renewables Photonics, engineering physics	Minor subject for B.Sc. and M.Sc. degrees. Noncontinuous and algorithmic reasoning in computer science, communication theory, optimization and mathematics.
Biomedical engineering	
Biological physics Biomedical engineering and imaging Modelling and 3D image processing Intelligent materials research	

The following pages provide information about the laboratories of the Department of Engineering Physics and Mathematics, the major subjects for the master's degree taught by the laboratories, and their research.



Experimental surface science is done in ultra high vacuum

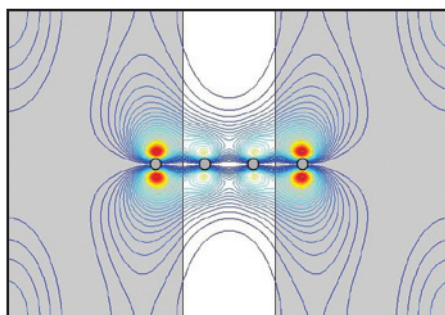
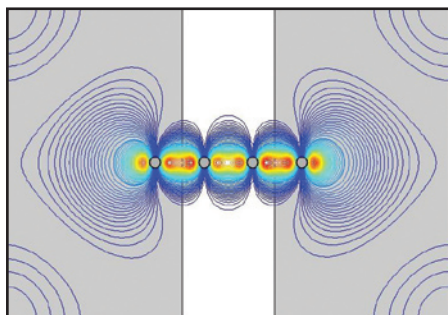
Engineering physics

Semiconductors, polymers
 Nanophysics and nanomaterials
 Positron physics, surface science
 Theoretical and computational physics
 Quantum mechanics
 and quantum computing
 Nonequilibrium phenomena
 and physical optimization
 Modelling of biological phenomena

The Laboratory of Physics is one of the largest units at TKK. The number of personnel exceeds one hundred, more than half of which are undergraduate or graduate students. The high quality of infrastructure and the tradition of working in research teams create favourable conditions for preparing master's and doctoral theses. The Laboratory of Physics has varied connections and intense scientific collaboration, including the exchange of researchers, with a great number of foreign universities and research institutes.

The computational physics group COMP, hosting researchers from 17 different countries, is the largest and most international research group within the Laboratory. It was selected as a "National Centre of Excellence" for the years 2000–2005, and again for 2006–2011. Theoretical and computational nanoscience research of COMP focus on properties of new materials, surface and interface phenomena, quantum and many body physics, non equilibrium phenomena, multiscale statistical physics and biological physics and are carried out in collaboration with various experimental groups.

The experimental physics group of our laboratory concentrates on materials research using positron spectroscopy and surface science techniques, e.g. in the study of defect structure of new semiconductor materials and properties of metal surfaces.

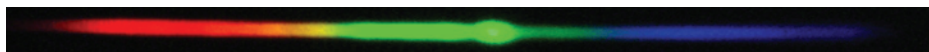


Electronic structure of a nanowire made of four carbon atoms

Laboratory of Optics and Molecular Materials

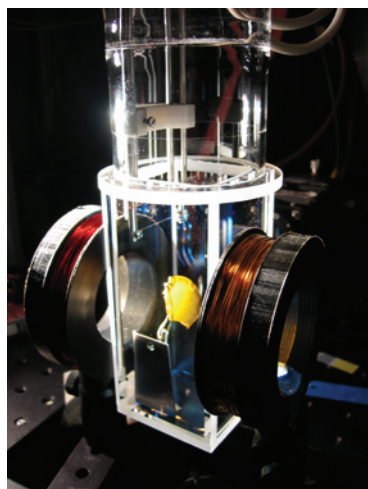
omm.hut.fi

Optics	Nanotechnology
Laser physics and quantum optics Photonics and nano-optics	Molecular materials Nanostructures and nanotubes

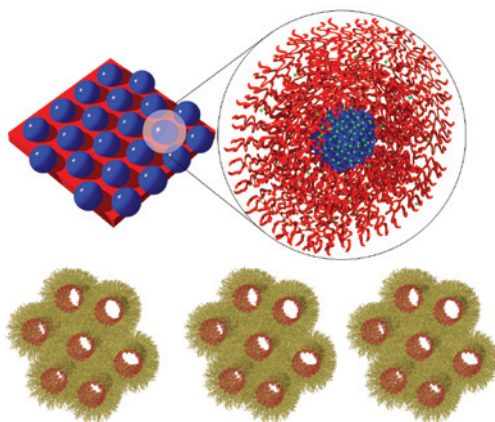


Lasers, communication by sending photons in optical fibers across the continents, and other inventions of modern optics have in many ways revolutionized our everyday life. A new revolution is already waiting behind the door, as applications of nanotechnology are reaching the markets. All these exciting new topics are investigated and taught at the OMM laboratory, where the research work extends from basic research to applications developed in collaboration with industry.

The OMM laboratory is part of the BIONANO centre of excellence of the Academy of Finland with its research focused on functional polymeric nanostructures and their applications in materials science, photonics and biotechnology. The nanostructures can be exploited in biotechnology for instance in bone tissue engineering and in implants. Other applications of nanostructures studied in the laboratory include conducting polymers, photonic crystals and functional membranes.

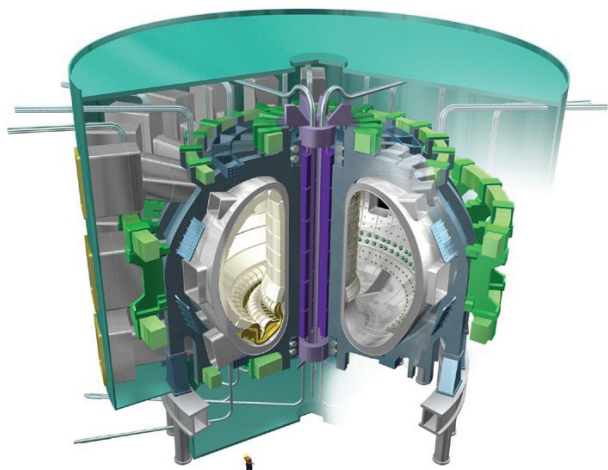


Trap for cold atoms



Polymeric nanostructures

Laboratory of Advanced Energy Systems



International fusion reactor, ITER, to be built in France

www.tkk.fi/Units/AES/

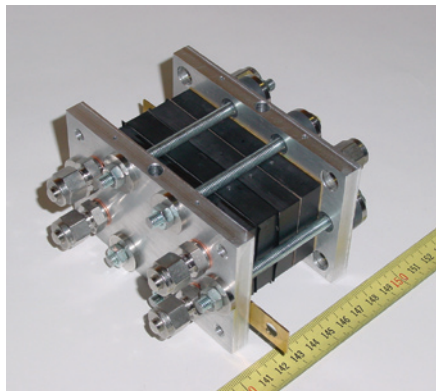
Advanced energy systems

Fusion energy,
plasma physics
Nuclear engineering,
radiation physics
New energy technologies,
renewables
Photonics,
engineering physics

Energy is one of the most strategic resources in modern society. Future energy solutions are knowledge-based, not raw-material based, and they require sophisticated technologies that rely on physics research. In the Laboratory of Advanced Energy Systems, current research topics include plasma physics, fusion reactors, distributed energy systems, hydrogen fuel cells and nano-structured solar cells. Projects on radiation physics and photonics are also part of the curriculum. The research is both theoretical and experimental, with strong international contacts.



Long-term field testing of solar modules



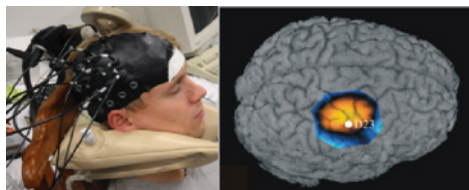
A small scale polymer fuel cell developed at the laboratory

Laboratory of Biomedical Engineering

biomed.tkk.fi

Biomedical engineering

Biological physics
Biomedical engineering and imaging
Modelling and 3D image processing
Intelligent materials research



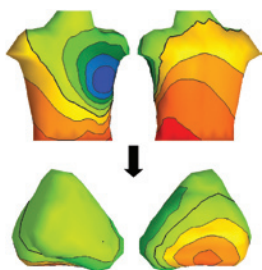
Infra-red imaging of brain activity



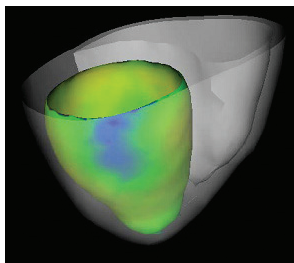
Bioelectric source localization in the brain

Biomedical Engineering is a rapidly developing field. It utilizes knowledge of living matter — from the molecular level to physiological systems. Companies are strongly involved not only in hi-tech product development, but also in research.

Laboratory of Biomedical Engineering acts as a part of the national centre of excellence “Helsinki Brain Research Centre”. The main research areas are bioelectrical phenomena of the heart and brain, signalling mechanisms of neurons, transcranial magnetic stimulation, novel medical imaging methods, and medical image processing. The research work is carried out in collaboration with research centres, companies, and Helsinki University Central Hospital.



ECG map and the computed potential distribution on the surface of the heart



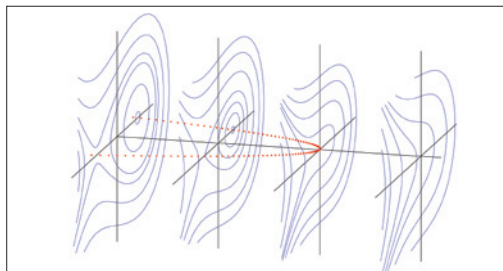
Positron emission tomography of the heart

Institute of Mathematics

math.tkk.fi

Mathematics

Mathematical analysis
Linear algebra, scientific computing
Partial differential equations
Inverse problems, imaging
Iterations and complex dynamics
Stochastics, risk management
FEM models and numerical analysis



Fold bifurcation of a Hamilton's system

Mechanics

Continuum mechanics
Modelling of structures and materials
Computational fluid dynamics

Computational science and engineering

Minor subject for B.Sc. and M.Sc. degrees.
Produces new scientific knowledge by computational means. Uses mathematical models, simulations and visualization.

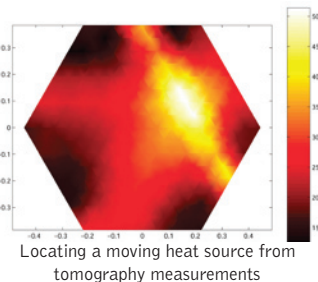
Discrete mathematics

Minor subject for B.Sc. and M.Sc. degrees.
Noncontinuous and algorithmic reasoning in computer science, communication theory, optimization and mathematics.

The Institute of Mathematics is TKK's biggest science and teaching unit with its nine professors. A mathematics student at TKK is a student of this whole community. He or she gets to choose from a wide palette that covers the theoretical as well as the applied. Collaboration is active with partners both in Finland and abroad. The institute has co-ordinated several international visitor programmes. Top researchers from foreign countries visit the institute frequently.

The researchers of inverse problems at the institute form part of the national Centre of Excellence of Inverse Problems Research appointed by the Academy of Finland, in close collaboration with other Finnish universities. The institute also participates in several national graduate schools. Computational methods are needed in an increasing number of applications, and the institute has joint research projects with representatives of many application areas, most notably in natural sciences and engineering.

The profile of the Institute of Mathematics gives its students an excellent training for a wide range of careers, such as a purely academic mathematician, an applied scientist or a mathematics engineer in industry.



Locating a moving heat source from tomography measurements

Systems Analysis Laboratory

www.sal.tkk.fi



Support for group decision making



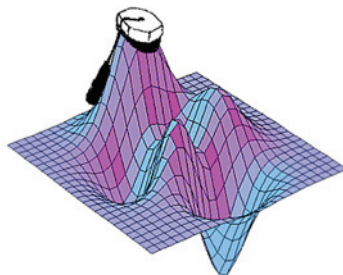
Optimisation of production and business processes

Systems Analysis Laboratory carries out research into mathematical models of engineering economic systems, decision making and decision support methodologies and systems thinking. Research topics include, among others, optimisation models of large scale systems, risk analysis, investment science, technological forecasting, decision analysis, game theory, implementation of mathematical algorithms, computer-aided decision support, teledemocracy, and models in energy economics and management of natural resources. There are exciting research opportunities in the area at TKK as well as at many research institutes.

The laboratory is responsible for the graduate school on Systems analysis, decision making and risk management. The graduate school collaborates actively with several leading research units abroad. The international mobility of both graduate and doctoral students is actively promoted.

Systems and operations research

Optimization, decision analysis,
game theory
Investment theory
Risk and technology assessment
Energy and environmental systems
Applied philosophy and
system intelligence



A two-dimensional visualisation of an optimisation problem

Engineering physics and mathematics

— a solid basis for science and industry

Like many other TKK physicists, Esa Korvenmaa chose to study engineering physics — “because it was hard to get in”. After studying nuclear technology as his major and applied mathematics as his minor, he graduated in 1979. He started his career in a company developing operation control systems for sawmills. After visiting America at the beginning of the 1980’s as a teacher of mathematics and programming, in 1983 he joined Hewlett-Packard, where he ascended to CEO of HP Finland. After a short while spent at Nokia, he returned to HP to managerial duties on a European scale. During 2000–2002 Esa Korvenmaa acted as CEO of the information security company Stonesoft, and then, until 2006, as Chief Operating Officer at TeliaSonera Finland. In August 2006 he will start as CEO of Cisco Systems Finland.

— Your career has nothing to do with nuclear technology that you studied as your major subject. Did you actually make a mistake when you started to study physics?

“Not at all, on the contrary. I am proud of my background in physics and I announce it openly.” Mr. Korvenmaa says that studying physics has given him the kind of practice in analytical thinking, managing complex matters and absorbing new, complicated things, which he might otherwise not have learnt. And above all, surmounting challenging studies has given self-confidence that has been useful when faced with any difficult problems, even if they have no direct connection with physics, as has been the case at least of late.

As he went ahead in his career, his tasks of an expert changed gradually into general managerial duties, where the ability to quickly absorb new, complicated things has been of great use. Along the way, he has also needed to master a number of skills that he had not learnt at TKK. The economic, marketing and human resources management skills have been even surprisingly easy to acquire through work. Mr. Korvenmaa also notes that had his studies only concentrated on such “soft” subjects, his sub-

“I am proud of my background in physics”



So far, all of Esa Korvenmaa's positions have been within information and communication technology industry. When he started, the area was new and only starting to get its form. As such, it suited very well a young and enthusiastic engineering physicist.

stance expertise would have remained quite thin in a rapidly developing area of technology. “Now my background allows me to put the right questions to those who develop the technology.” By the arguments above, he has also found it easy along the years to hire engineering physicists for demanding tasks, when he has been able to trust their strong competence.

Esa Korvenmaa says that he has never actually planned his career. When offered new challenges, however, he has tried to seize them with vigour, and he remarks that “about three years in one job has been long enough. Even though in a new position, and in particular in a new company, one must always re-prove one's competence and gain the confidence of the community, changing jobs has always been rewarding.” The networks he created already during his studies have been useful in many ways. Mr. Korvenmaa was president of the Guild of Physics for two years. When negotiating with someone with a common background and similar experiences, it is often easier to find a solution.

The research student's point of view

M.Sc. (Tech.), researcher Riikka Kangaslampi



Why did you come to study at the Department of Engineering Physics and Mathematics of TKK?

— Mathematics and physics started to fascinate me in high school more and more. I noticed that they were not difficult for me, and that solving problems gives a wonderful feeling.

I found out which universities you can study mathematics at. I chose TKK, because here the first years give a good all-round education also in computing, physics etc., and the selection of majors is wide.

The fact that entrance was not a pushover was another sign of the high level. I got in

without an entrance examination on the grounds of my success in the high school mathematics competitions. It has been fun to continue this hobby at the International Mathematics Competition for University Students, where the institute of mathematics has every year sent a team that has done relatively well.

What made you choose mathematics as your major?

— I got acquainted with mathematics during my first years of study through the mathematics courses, but also as a teaching assistant, when I was giving the exercise sessions of the basic courses of mathematics.

The exactness of mathematics made an impression on me. No guesswork, approximations or unjustified generalizations, but rigorous and precise science. I am a very thorough person and I want to understand things in depth, and in mathematics I have the opportunity for that. And besides, mathematics is beautiful!

Why did you decide to pursue graduate studies?

— When studying for my master's degree I realized that I like teaching and research, so graduate studies seemed a natural choice. As I studied further, I ran into even more interesting topics — I wanted to learn more.



The Guild of Physics



www.fysikkokilta.fi



The Guild of Physics (Fysikkokilta) is the association of students of engineering physics and mathematics. Like other student associations, the guild brings together students of a certain field.

In practice, bringing students together means arranging many types of activity. The guild arranges sports, culture, sauna evenings, parties, dinners etc. Something for everyone.

The guild's activities are not, however, restricted to recreational activities for its members, but the guild also supervises the interests of students, for instance with regard to the department. We also make excursions to local companies, and sometimes further afield as well.

The guild is a splendid way to get to know others studying in the same area, future colleagues.

P.S. Although studying mathematics and physics might not be too hip, there is always a shortage of experts in the area, and career opportunities are quite varied and challenging.



Helsinki University of Technology TKK
Department of Engineering Physics and Mathematics
<http://www.tkk.fi/Units/EngineeringPhysics/>

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