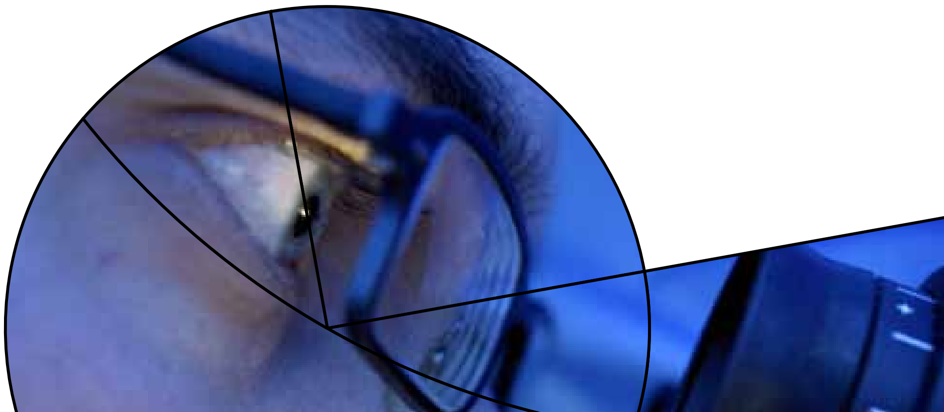
NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Nano-Science Center

Nanoscience and nanotechnology plays a key role within a broad range of future technologies. The Nano-Science Center encompasses the research efforts at the University of Copenhagen in this important field.
At the Centre we feel strongly committed to transferring knowledge and know-how to industrial partners. To support that aim, we have prepared a brief introduction to our activities and short descriptions of a selection of our research groups.

Morten Meldal,
Director of Nano-Science Center
March 2011



Nano-Science Center

New materials, new drugs, new methods in diagnostics and new ways of harvesting energy or integrating food quality monitoring are just a few of the scenarios for which basic nanoscience research offers great potential.

The Nano-Science Center is where the activities at the University of Copenhagen relating to nanoscience research, education, and technology are gathered.

Research

The Centre possesses state-of-the-art research infrastructure and expertise in semiconductor nanostructures, molecular and polymer electronics, synchrotron X-ray physics, carbon nanotubes, theory, supramolecular chemistry and self-assembly, bionanotechnology, nanogeoscience, nanomedicine, organic synthesis, and more.
Nano-Science Center was established in 2001, when researchers from the Physics and Chemistry Departments at the University moved in together. As a reflection of the merger in 2007 between University of Copenhagen, the Royal Veterinary and Agricultural University and the Danish University of Pharmaceutical Science, the Nano-Science Center now includes a Centre for Pharmaceutical Nenotechnology and Nanotoxicology (CPNN) and emerging efforts in Synthetic Biology.

Today the Nano-Science Center is staffed by 20 full-time faculty members, 5 permanent technical staff and about 72 postdoctoral researchers, PhD students and guest researchers. The Centre produces some 120 peer-reviewed publications annually with faculty members receiving about 6000 citations every year; on average, their entire scientific production has been cited more than 20 times per paper so far. This has attracted more than 550 MDKK in external funding (2001-jan 2011). Bachelor, Master's and PhD programmes in nanoscience have also been successfully launched, with the number of students enrolled for the Bachelor and Master's programmes totaling more than 200.

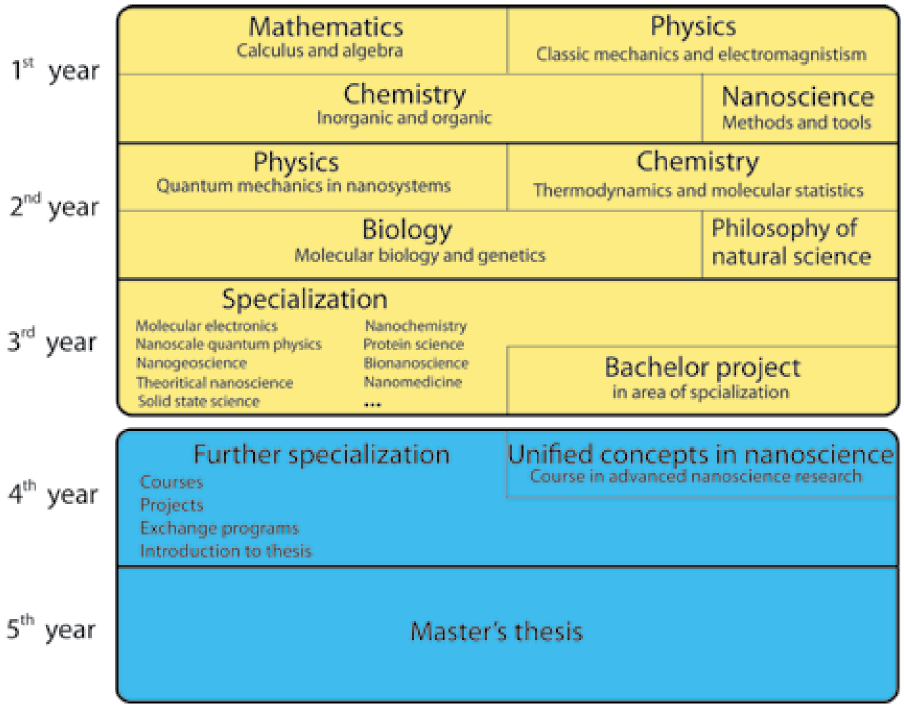
Nanoscience education

Good education is of paramount importance for a knowledge-based society. Since 2002 the University of Copenhagen has offered a nanoscience education with an initial focus on interdisciplinary studies and the possibility of specialising later on.

The first two years of the curriculum are based on introductory courses that cover the basic concepts of chemistry, physics and biology. Interdisciplinary laboratory exercises cover all the relevant tools for the construction and investigation of nature at the nanometer scale. The introductory courses are followed by a catalogue of more advanced courses enabling the student to specialise in specific areas of interest, such as nano-physics, nano-chemistry and nano-biotechnology. Many students take the opportunity to obtain part of their education abroad. The figure below outlines the education in nanotechnology. The Bachelor degree is obtained after three years but most of the Nano-Science students graduate with a Masters degree after further two years.

The bachelor and master programmes include individual research projects, that are carried out in research groups in the Nano-Science Centre, at other faculties or in collaboration with industrial partners. We are aiming at 20% of all student projects completed in collaboration with industrial partners.

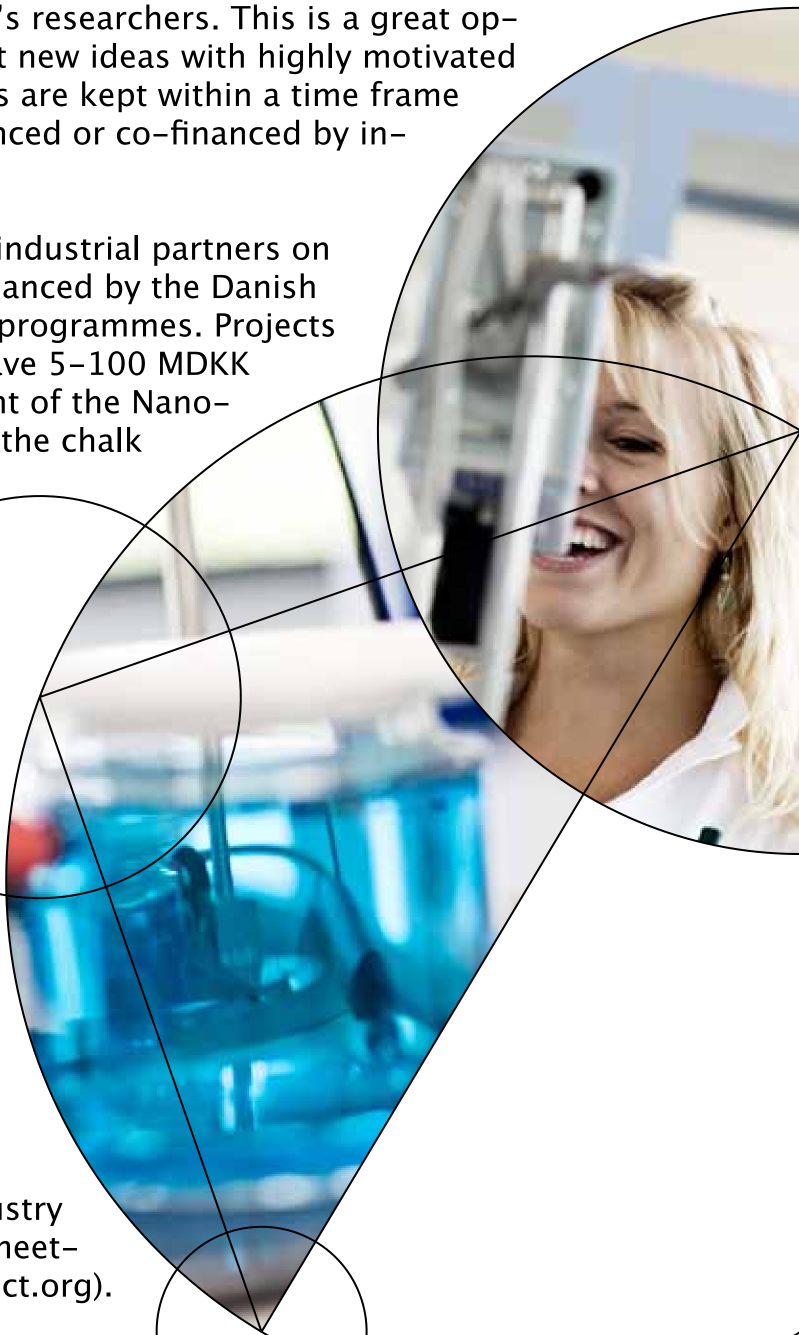
For more information, contact Head of Education:
Per Hedegård, hedegard@nano.ku.dk



Collaborations with industry and technology transfer

Technology transfer and collaboration with industry is a high-priority area. The Nano-Science Center entertains more than 40 active collaborations with 23 industrial partners (Jan. 2009). In the form of student and PhD projects, as well as larger scale research projects.

Student projects are typically completed within 1-12 months, allowing interaction with researchers from industry. Each project is supervised by both a Nano-Science Center researcher and one of the industrial partner's researchers. This is a great opportunity for the industrial partner to try out new ideas with highly motivated students pro viding inspiration. PhD projects are kept within a time frame of 3-4 years. PhD projects are typically financed or co-financed by industrial partners.



The Nano-Science Center collaborates with industrial partners on larger-scale projects, which are often co-financed by the Danish State or take the form of projects within EU programmes. Projects of this type usually run for 3-5 years and have 5-100 MDKK budgets. Examples include the establishment of the Nano-GeoScience research group's exploration of the chalk of North Sea, using a range of nano-scale techniques. One goal is to improve oil recovery. The project is co-financed by Maersk Oil and Gas AS, the University of Copenhagen and the Danish State through the High Technology Foundation and some other grants; the total budget is about 70 MDKK.

Basic research is needed to develop new business ideas and create new high-tech jobs. The Centre has been involved in the start-up of several new companies.

The Centre participates in the development of regional and national networks such as Nano-Øresund, which is a network focusing on bringing players from academia and industry closer together. The tools include network meetings, science-dating, etc. (www.nano-connect.org). For more information, contact:

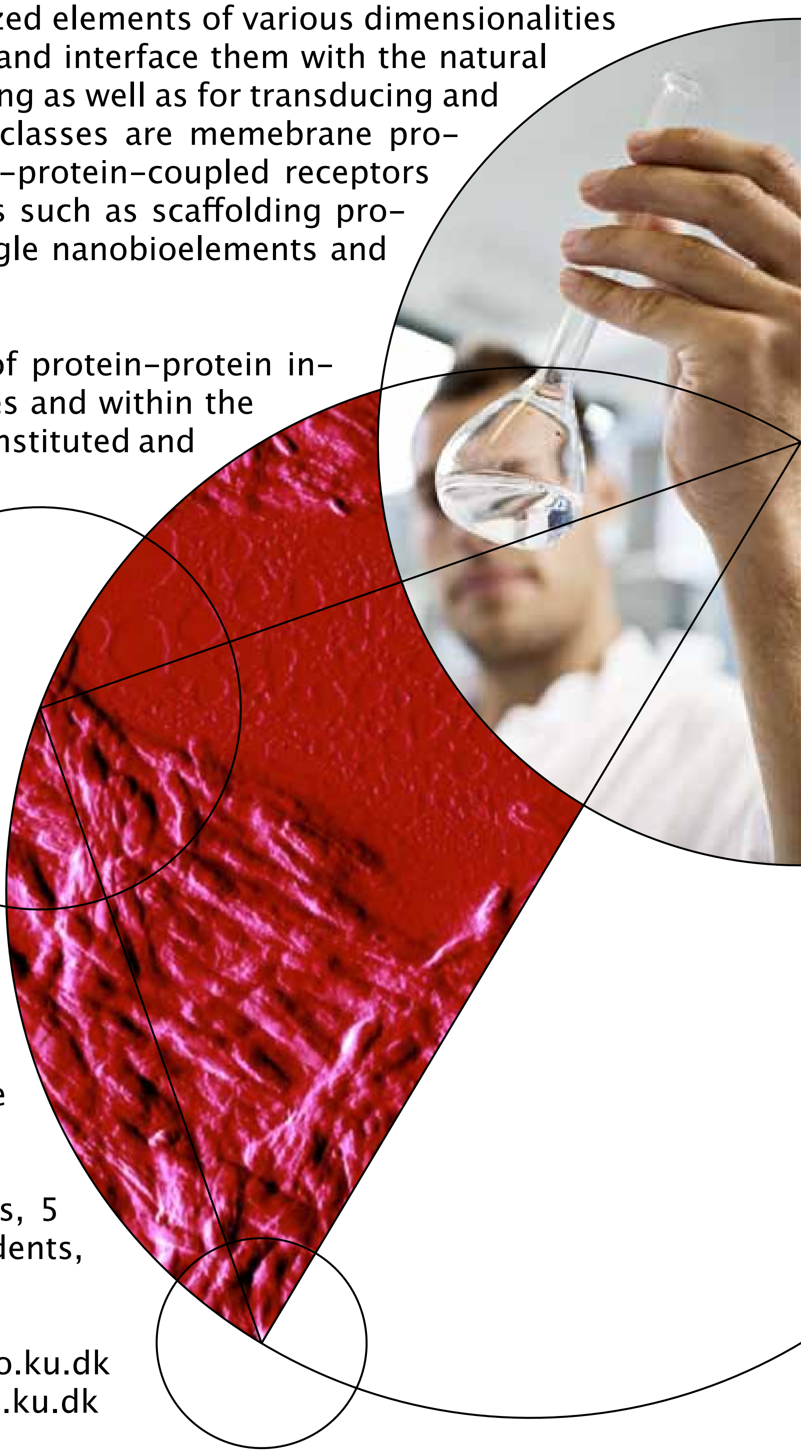
Morten Christensen, mc@fys.ku.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Bio-Nanotechnology Group

The Laboratory has two primary scientific goals. To develop biologically inspired nano-sensors and understand the structure and function of nanoscale biological systems.

Bio-nanosensors: We aim at developing novel platforms suitable for low- and high-throughput screening to be used for proteomics, diagnostics (monitoring analyte concentrations in living cells or physiological liquids) and therapy (drug screening, drug delivery). For this purpose we engineer nanosized elements of various dimensionalities (nanoparticles, nanowires, nanocontainers) and interface them with the natural biomolecular systems used by cells for sensing as well as for transducing and amplifying signals. Representative protein classes are memebrane proteins such as ion channels, transporters, G-protein-coupled receptors (GPCRs) and membrane-associated proteins such as scaffolding proteins. The emphasis is on manipulating single nanobioelements and multiplexing their response.



Nanoscale protein assemblies: A plethora of protein-protein interactions take place at membrane interfaces and within the heterogeneous lipid matrix itself. Using reconstituted and native lipid membranes, we try to understand the nature of the influence of nanoscale membrane composition, internal structure, shape, etc. on the interactions of transmembrane proteins (e.g. oligomerization) and membrane-associated proteins. Systems studied include GPCRs, scaffolding proteins, the SNARE complex, BAR domains and protein coats.

Keywords: bionanosensors, nanowires, nanoparticles, nanocontainers, confined reactions, artificial and biological membranes, adaptor proteins, scaffolding complexes, membrane proteins, single-enzyme activity.

Personnel: Currently 2 associate professors, 5 post-Docs, 9 PhD students, 6 Master's students, and 7 BSc students

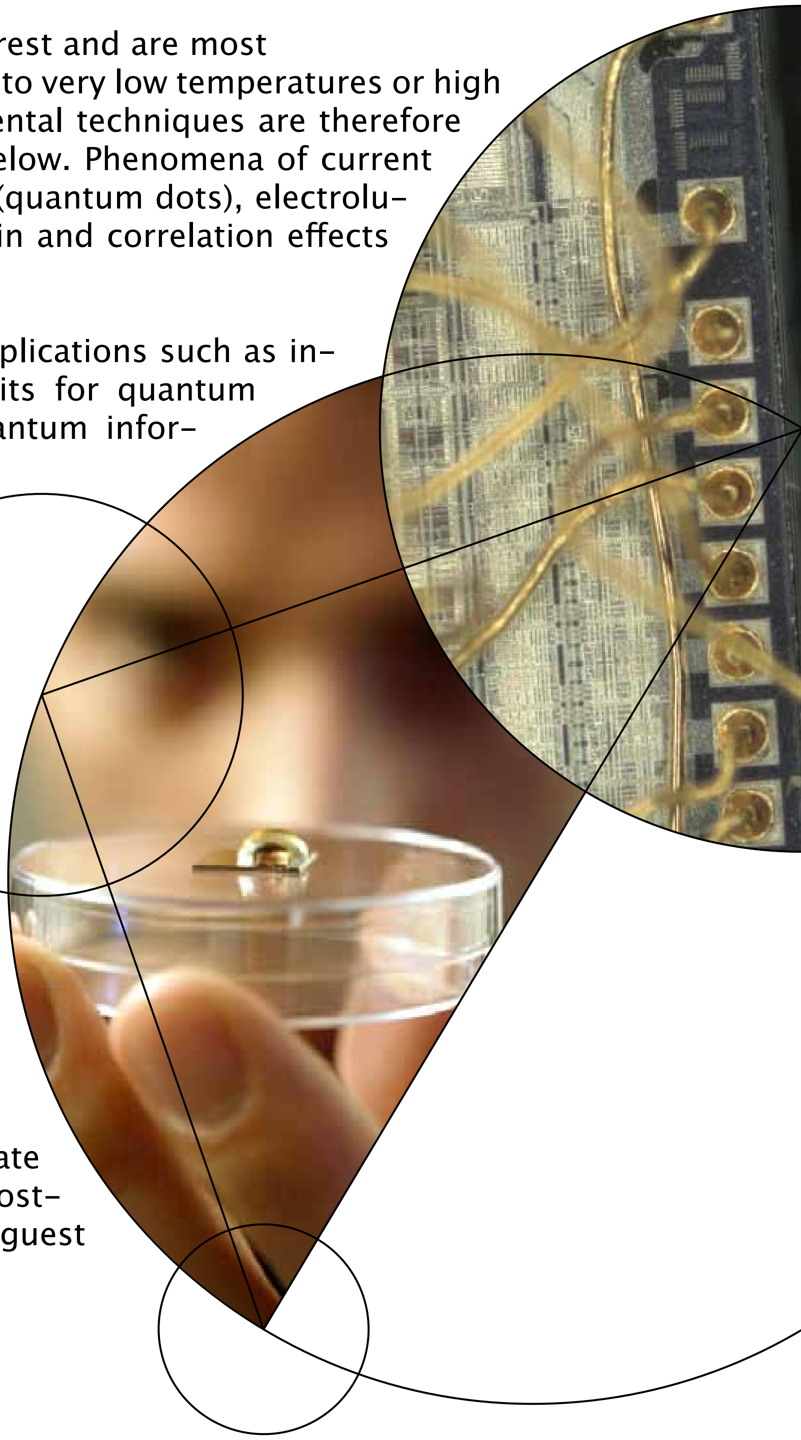
Contact: Dimitrios Stamou, stamou@nano.ku.dk
Karen Martinez, martinez@nano.ku.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Nanoelectronics Group

The group focuses on experimental studies of nanoscale electronic devices based on, for instance, carbon nanotubes and semiconductor nanowires. We grow these materials in-house and make devices using state-of-the-art nanofabrication techniques. In particular, we are able to attach nanoscale electrodes to individual nanostructures in order to measure their electrical properties. The devices may incorporate magnetic or superconducting elements.

Novel quantum effects are of particular interest and are most clearly shown when the devices are exposed to very low temperatures or high magnetic fields. A wide palette of experimental techniques are therefore employed to realise our studies as listed below. Phenomena of current interest include single-electron transistors (quantum dots), electroluminiscence from nanodevices as well as spin and correlation effects in electron transport.



Our work may lead to a variety of future applications such as integrated nanoelectronics, spintronics, qubits for quantum computing, single-photon sources for quantum information, photovoltaics, and sensor technology.

Techniques: Electron-beam and optical lithography, molecular-beam epitaxy (III-V materials), chemical vapour deposition (carbon nanotubes, silicon), clean-room processing, thin-film deposition, ultra-sensitive electrical measurements, low-temperature techniques (sub-Kelvin), high magnetic fields, optoelectronic measurements, atomic and electrostatic force microscopy, scanning probe manipulation, scanning and transmission electron microscopy

Personnel: Currently 1 professor, 2 associate professors, 5 assistant professors and post-Docs, 3 technical staff, 3 PhD students, and guest researchers

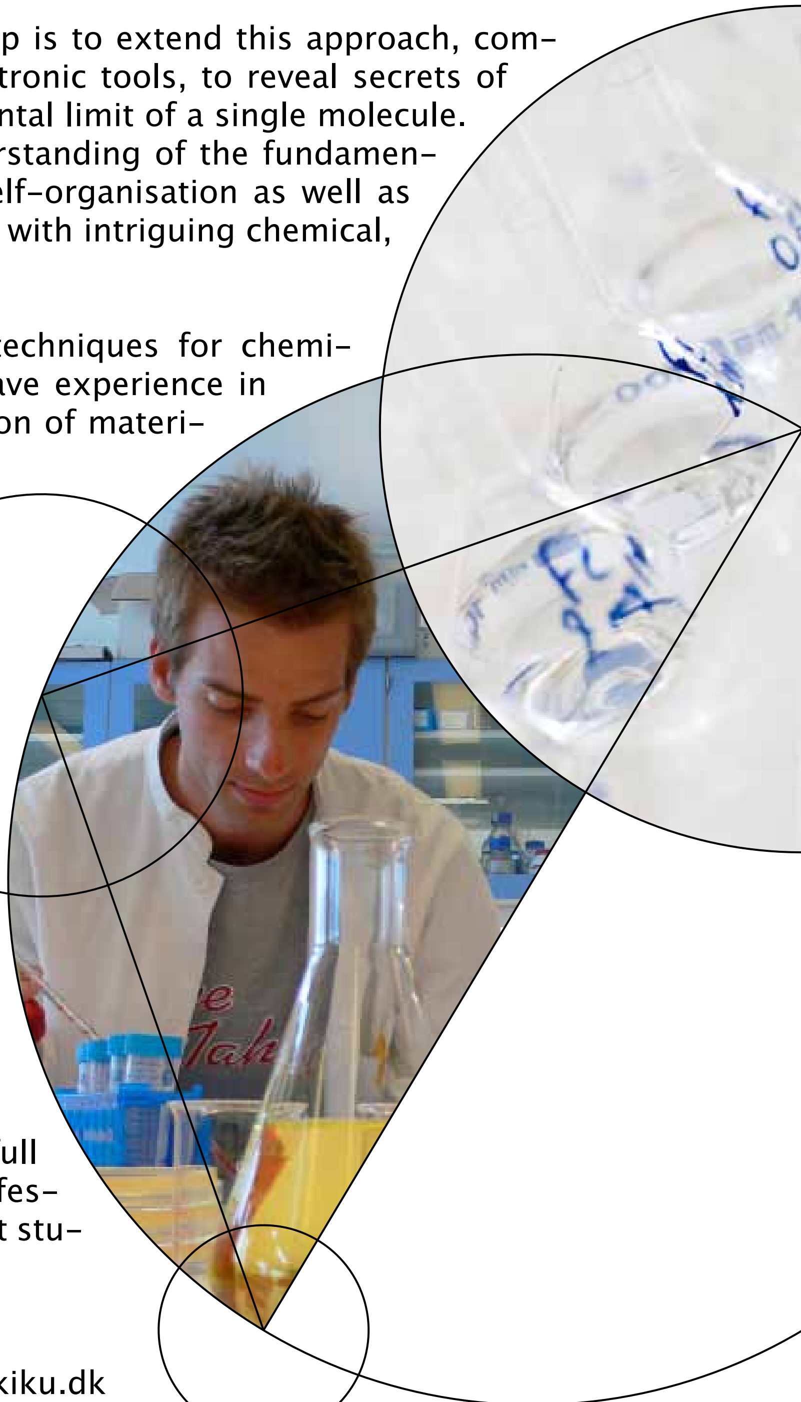
Contact: Jesper Nygård, nygard@nbi.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Nanochemistry Group

The Nanochemistry Group seeks to define and exploit the laws governing self-assembly, quantum effects, electron and energy transfer and other fundamental nanoscale phenomena. Chemists can make new systems and study how properties change through systematic structural variation at the molecular level. Through this line of research the group is making a strong and very important contribution to the broad interdisciplinary field of nanoscience.

The overall aim of the Nanochemistry Group is to extend this approach, combined with new structural, optical and electronic tools, to reveal secrets of nanoscale assemblies down to the fundamental limit of a single molecule. In particular, we wish to develop our understanding of the fundamental principles of chemical and biological self-organisation as well as the intrinsic properties of new nanosystems with intriguing chemical, biological or physical properties.



Techniques: In addition to the classical techniques for chemical preparation and characterisation, we have experience in methods and techniques for the investigation of materials down to the single-molecule level. Our library of methods includes atomic force microscopy, fluorescence microscopy, Langmuir-Blodgett techniques, ultrahigh-vacuum deposition techniques, time-resolved spectroscopy, dynamic light-scattering (DLS), various surface-active X-ray techniques, and electrochemistry.

Keywords: molecular electronics, artificial photosynthesis, catalysis, chirality, drug delivery, biomimetic catalysis, artificial enzymes, dendrimers, conducting polymers, electrochemistry, sensors, new fluorophores, and surface chemistry.

Personnel: The group currently counts 4 full professors, 6 assistant and associate professors, 23 PhDs and post-Docs, and 33 project students.

Contact: Bo Wegge Laursen, tb@nano.ku.dk
Mogens Brøndsted Nielsen, mbn@kiku.dk
Mikael Bols, bols@kemi.ku.dk

NanoGeoScience Group
Environment and Energy

Our research explores the fundamental physical and chemical principals controlling processes in natural systems. To understand molecular-level reactions at the interface between soil or rock, water and air, we use techniques that let us to "see" at the nanometer scale.

Some of our projects aim to understand what determines drinking-water quality and to develop environmentally friendly ways to treat contaminated water. We have worked for many years to discover the properties of soil minerals and to improve their ability to immobilise toxic components such as heavy metals, pesticides, solvents and radioactive compounds, so that waste can be disposed of responsibly. Study of fluid interaction with solids gives insight into how organisms make minerals such as bones, teeth and shells. Better understanding of biomineralisation has implications for treating arthritis or osteoporosis, for example. Our largest project at present is exploring the properties of chalk so we can modify its behaviour and extract more oil from the North Sea. Recently, we were invited to take part in a project that will develop a method for converting CO_2 into rock, so it will be permanently removed from the atmosphere.

Methods: In addition to the classical analytical methods for characterising fluids and solids (spectroscopy, chromatography, potentiometry, diffraction, scintillation counting, BET, etc.) we investigate nanoparticles and interfaces a few molecular layers thick. Facilities include: atomic force and other scanning probe microscopies, X-ray photoelectron, ultraviolet and Auger electron spectroscopies and low-energy electron diffraction. We also use scanning and transmission electron microscopy and a range of synchrotron radiation-based techniques.

Personnel: We have 35 full and associated members, including professors, post-docs, PhD and Masters students and guests.

Contact: Susan L. Svane Stipp, stipp@nano.ku.dk

Theory for Nanosystems

The interaction of theory and experiment is of paramount importance to an understanding of nature. Understanding electrical transport through nanoscopic objects requires a joint scientific effort combining different scientific disciplines such as chemical and physical experiments and theories.

The experiments give rise to questions that cannot be described within the established theoretical framework. Consequently, new methods and new theory must be developed.

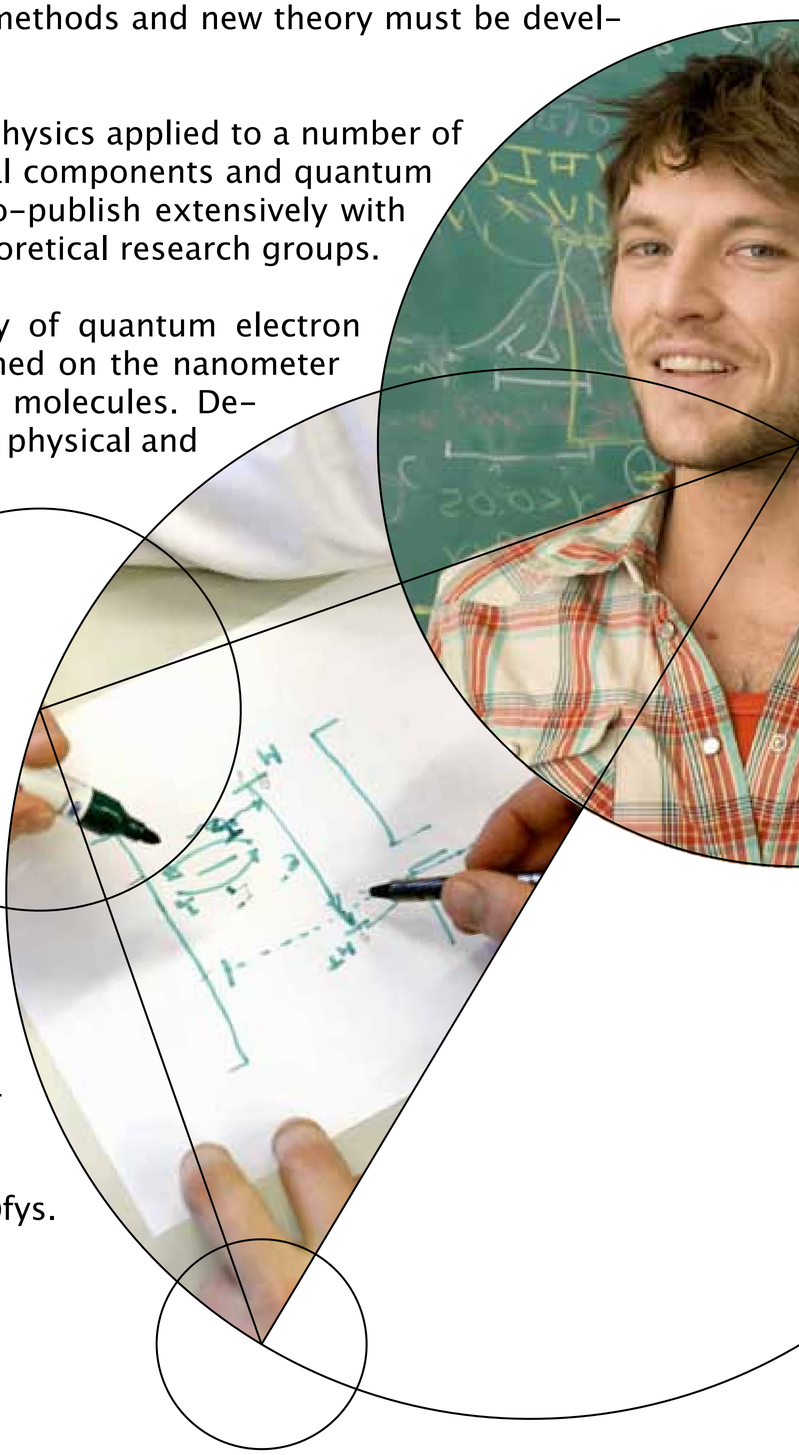
The research group works with theoretical physics applied to a number of nanoscopic systems, primarily nanoelectrical components and quantum information systems. We collaborate and co-publish extensively with several world-leading experimental and theoretical research groups.

The dominant activity concerns the theory of quantum electron transport through structures that are confined on the nanometer scale, including nanowires, fullerenes and molecules. Describing them involves a number of different physical and chemical effects, such as quantum coherence phenomena, correlation effects, electronic charging and dynamics of molecular vibrations, which are all joined together. This is done by numerical calculation based on microscopic parameters as well as by mathematical analysis of model systems.

Key Words: Mathematical modelling, computer simulation, quantum phenomena, electrical transport, many-body quantum theory.

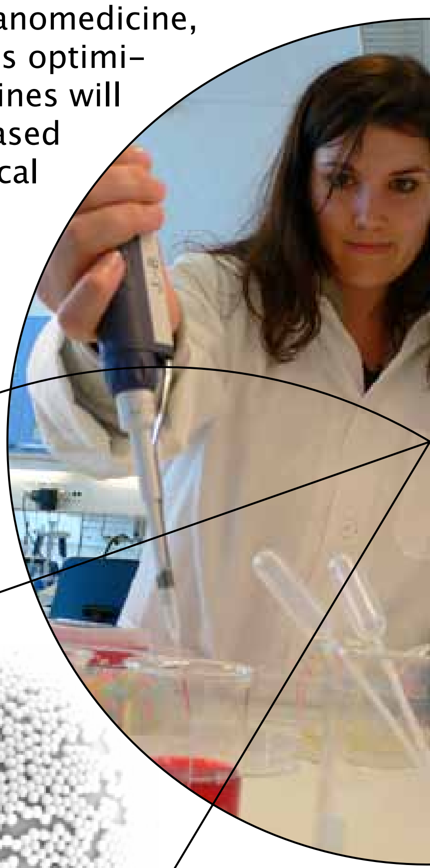
Personnel: The group currently counts 2 permanent professors, 2 assistant professors, 3 post-Docs, and 2 PhD students.

Contact: Karsten Flensberg, flensberg@fys.ku.dk

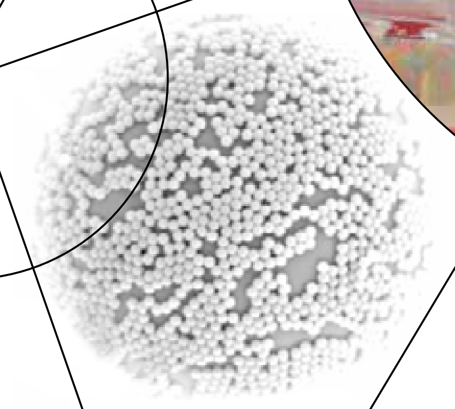


Centre for Pharmaceutical Nanotechnology and Nanotoxicology (CPNN)

The development of a wide spectrum of promising nanoscale materials, either in their own right or as a component of multifunctional platforms, is beginning to have a paradigm-shifting impact in medicine; they are changing the foundations of disease diagnosis, monitoring and treatment, and turning molecular discoveries into benefits for patients. Research into delivery and targeting of pharmaceutical, therapeutic, and diagnostic agents via intravenous and interstitial routes of administration with particulate drug carriers and nanoconstructs is at the forefront of projects in nanomedicine, but the biological performance of such delivery systems still requires optimization. However, the future of particulate and polymeric nanomedicines will depend on rational design of nanotechnology materials and tools based around a detailed and thorough molecular understanding of biological processes, rather than forcing applications for some materials currently in vogue. Therefore, the prime research focus of the Centre is to unravel the molecular basis of nanomaterial performance and toxicity through “structure-activity” assessments at membrane, organelle, cellular and animal level in combination with and by improving/optimizing the performance of the state-of-the-art bio-nanotechnology techniques. This integrated and multidisciplinary approach is expected to improve therapeutic benefit-to-risk ratio.



CPNN intend to provide “benchmark protocols” for toxicity evaluation of nanomedicines in animals, and at cellular and molecular levels, as the sensitivity and precision of the standard toxicological procedures are of arguable value in nanomedicine research and development as it is limited to spotting extreme toxicity.



Keywords: Drug delivery systems; Gene and nucleic acid transfer; Immunobiology; Immunological reactions; Liposomes; Nanomedicine; Nanoparticulate systems; Nanoparticle tracking; Nanoplatforms; Molecular toxicology; Polymeric constructs

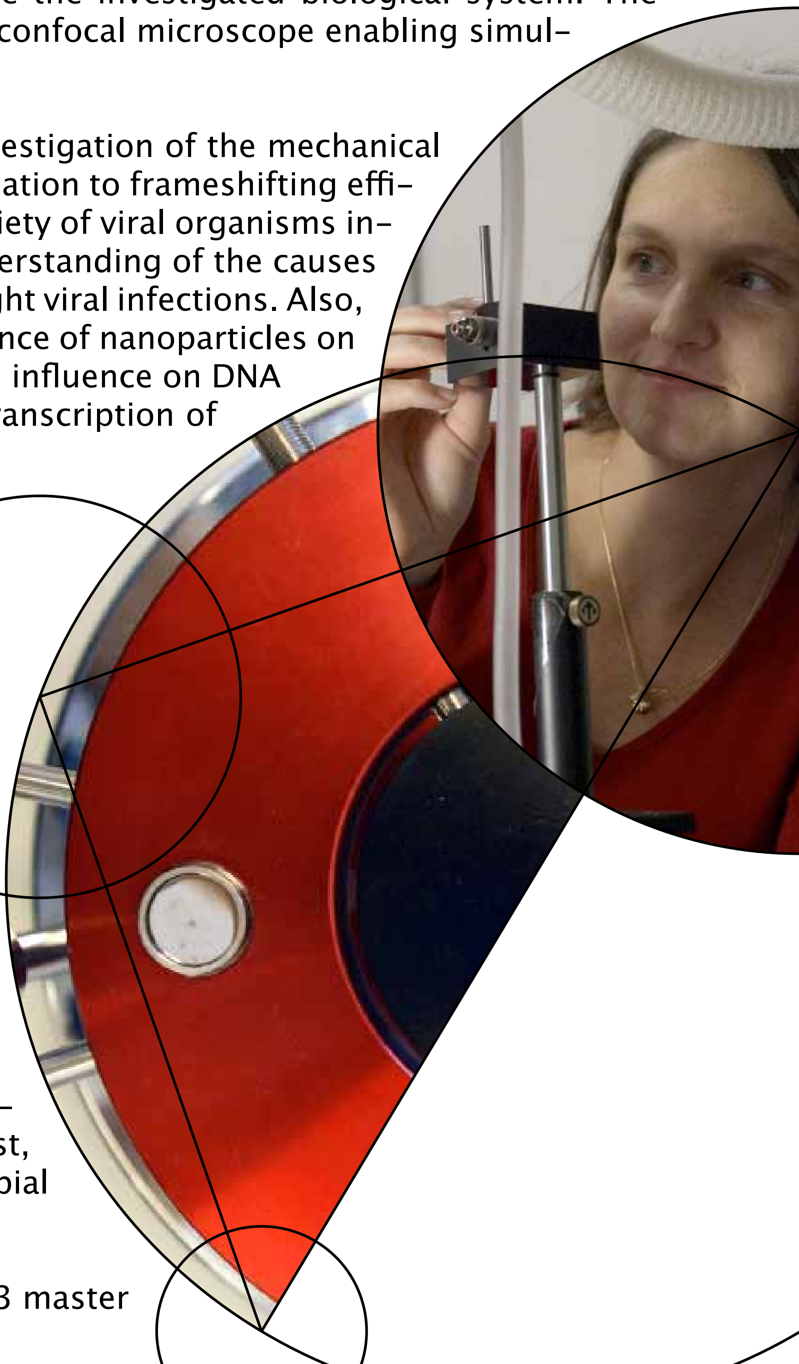
Contact: S.M. Moghimi, momo@farma.ku.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Optical Tweezers Group

The main goal of the optical tweezers group at the Niels Bohr Institute is to investigate physical properties of biological systems at the single molecule to cellular level.

The group has extremely efficient and stable optical trapping facilities, which enable trapping and manipulation of nanoparticles such as colloidal silver or gold particles, gold nanorods, and individual quantum dots. These particles are used as handles for the optical techniques to visualize and manipulate the investigated biological system. The optical trap ping facility is combined with a confocal microscope enabling simultaneous visualization.



The single molecule activities include an investigation of the mechanical stability of mRNA pseudoknots and its correlation to frameshifting efficiencies. This mechanism is utilized by a variety of viral organisms including HIV and avian virus; a thorough understanding of the causes of frameshifting will improve our ability to fight viral infections. Also, we investigate the possible hazardous influence of nanoparticles on DNA, in particular focusing on their possible influence on DNA elasticity, which is important for a correct transcription of the heritage material.

In vivo we study how a single protein, the lambda receptor, moves in the outer membrane of E. coli bacteria. Using antibiotics and antimicrobial peptides, we investigate how these influence the bacterial membrane thus obtaining knowledge on the function of antibiotics and antimicrobial peptides on a single molecule level. The work on antimicrobial peptides is done in collaboration with Novozymes A/S.

Key words: Optical trapping, confocal microscopy, single molecule biophysics, cell biophysics, mRNA pseudoknots, S. pombe yeast, E. coli bacteria, lambda receptor, antimicrobial peptides.

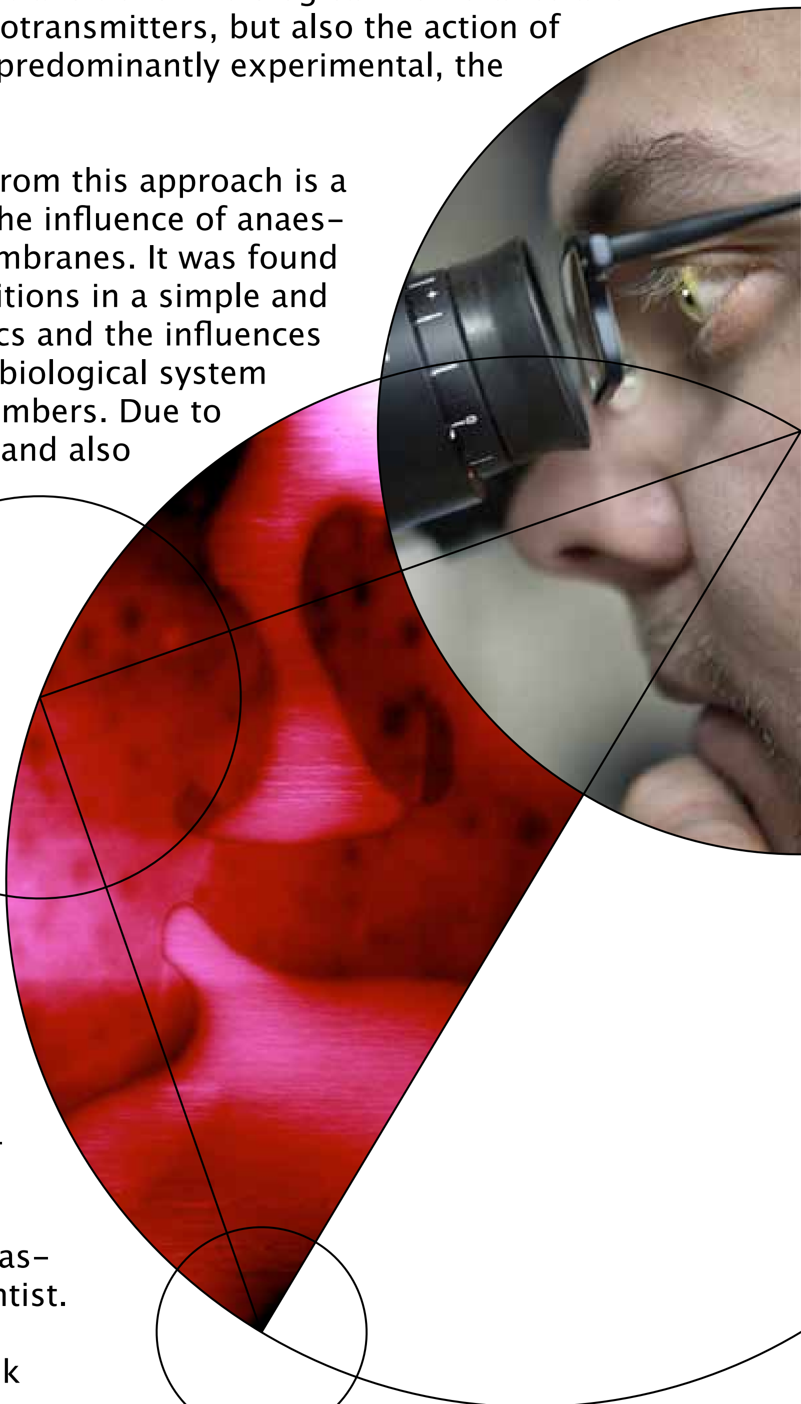
Personel: 3 postdocs, 7 graduate students, 3 master students, 2 adjoint professors

Contact: Lene Oddershede, oddershede@nbi.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Membrane Biophysics Group

The focus of the Membrane Biophysics Group is on the physical properties of ensembles of molecules beyond the single-molecule level, particularly those of biological membranes. The working hypothesis is that much biological action involves ensembles or groups of molecules and thus cannot be understood on the basis of binary binding reactions. The laws of thermodynamics provide strict couplings between different physical properties of biological systems that are often invisible or obscured at the single-molecule level. We study in particular phase transitions in biological membranes and the influence of proteins, anaesthetics, neurotransmitters, but also the action of proteins such as phospholipases. Although predominantly experimental, the Group has a strong theoretical foundation.



The Group's most recent success resulting from this approach is a theory for anaesthesia based on studies in the influence of anaesthetic molecules on phase transitions in membranes. It was found that anaesthetic drugs reduce melting transitions in a simple and predictable manner. The action of anesthetics and the influences of many parameters (pH, pressure) within a biological system can be predicted correctly in quantitative numbers. Due to the thermodynamic couplings, anaesthetics and also neurotransmitters can influence membrane permeability through their ability to cause structural and softness changes in the membranes.

Techniques: Fluorescence correlation spectroscopy, calorimetry, fluorescence microscopy, atomic force microscopy, infrared spectroscopy, statistical thermodynamics simulation, basic electrophysiology, etc.

Keywords: Biophysics of artificial and biological membranes, action of anaesthetics and neurotransmitters, nerves, phase transitions, elastic constants of biological membranes, lipid ion channels

Personnel: 2 post-Doc, 3 PhD students, 3 Master's students, 1 senior scientific guest scientist.

Contact: Thomas Heimburg, theimbu@nbi.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

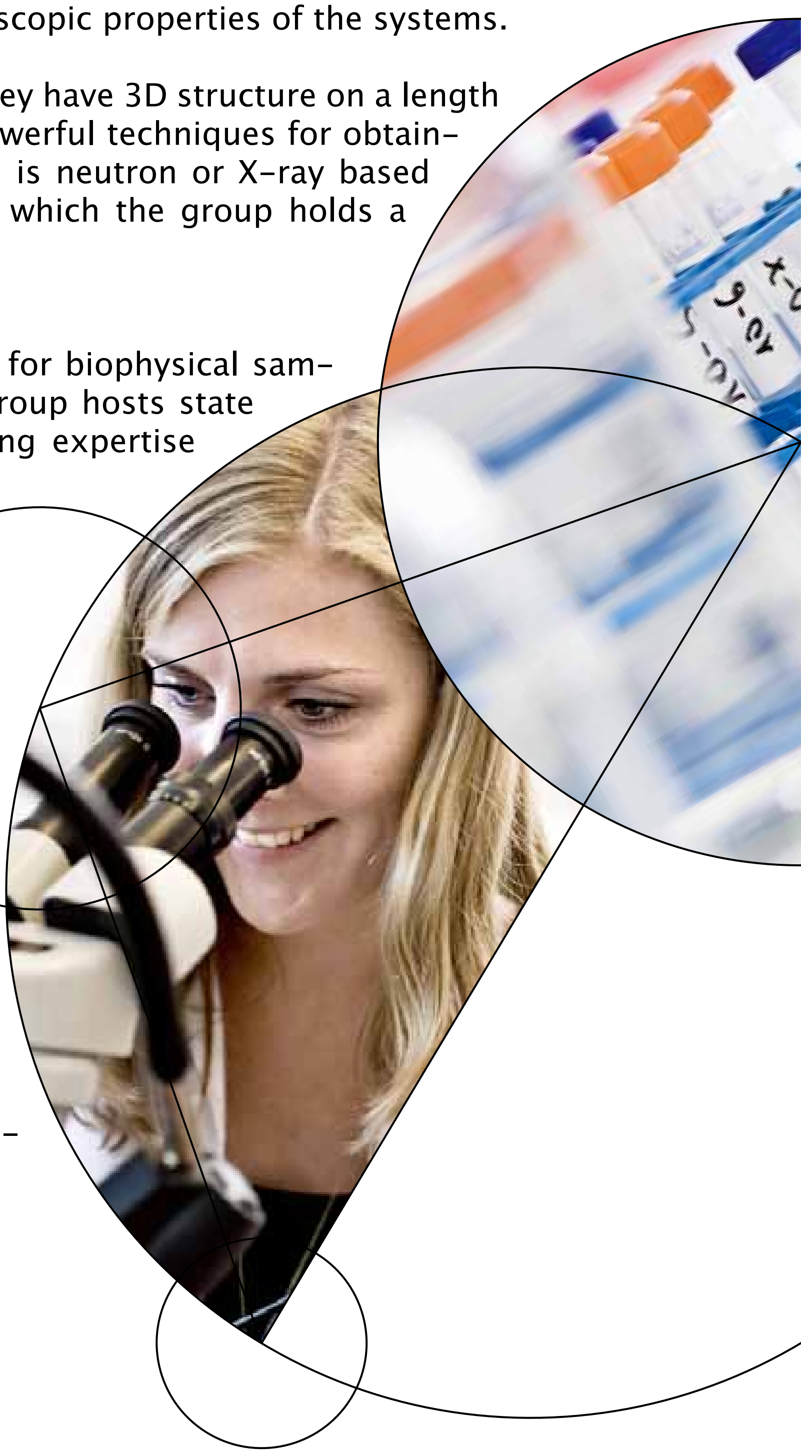
Scattering on BioNanosystems

The central focus of the group is to explore and understand structural properties of bio-macromolecules in solution as well as soft condensed matter systems. Typical examples are proteins or enzymes in solution, where the group seeks to elucidate the rules that govern the formation of protein-protein complexes, fibrils or more disordered aggregates. Other examples are amphiphilic self-assembling systems, including lipid membranes, surfactant or advanced polymer systems, where the group seeks to elucidate the relation between the nanoscale structure and macroscopic properties of the systems.

Characteristic for all these systems is that they have 3D structure on a length scale of 1-100 nm. At present, the most powerful techniques for obtaining structural information on such systems is neutron or X-ray based small-angle scattering (SANS and SAXS) in which the group holds a very strong expertise.

Techniques:
In addition to a range of standard facilities for biophysical sample preparation and characterization, the group hosts state of the art instrumentation and a very strong expertise within static and dynamic light scattering (SLS and DLS).

Small-Angle Scattering experiments (SAXS and SANS) are carried out at international large-scale facilities (synchrotrons and neutron facilities), where the group has a very strong network and expertise in managing both the experiments and the subsequent data analysis.



Keywords: Proteins, enzymes, dynamics of protein aggregation, biomembranes, polymers, soft condensed matter

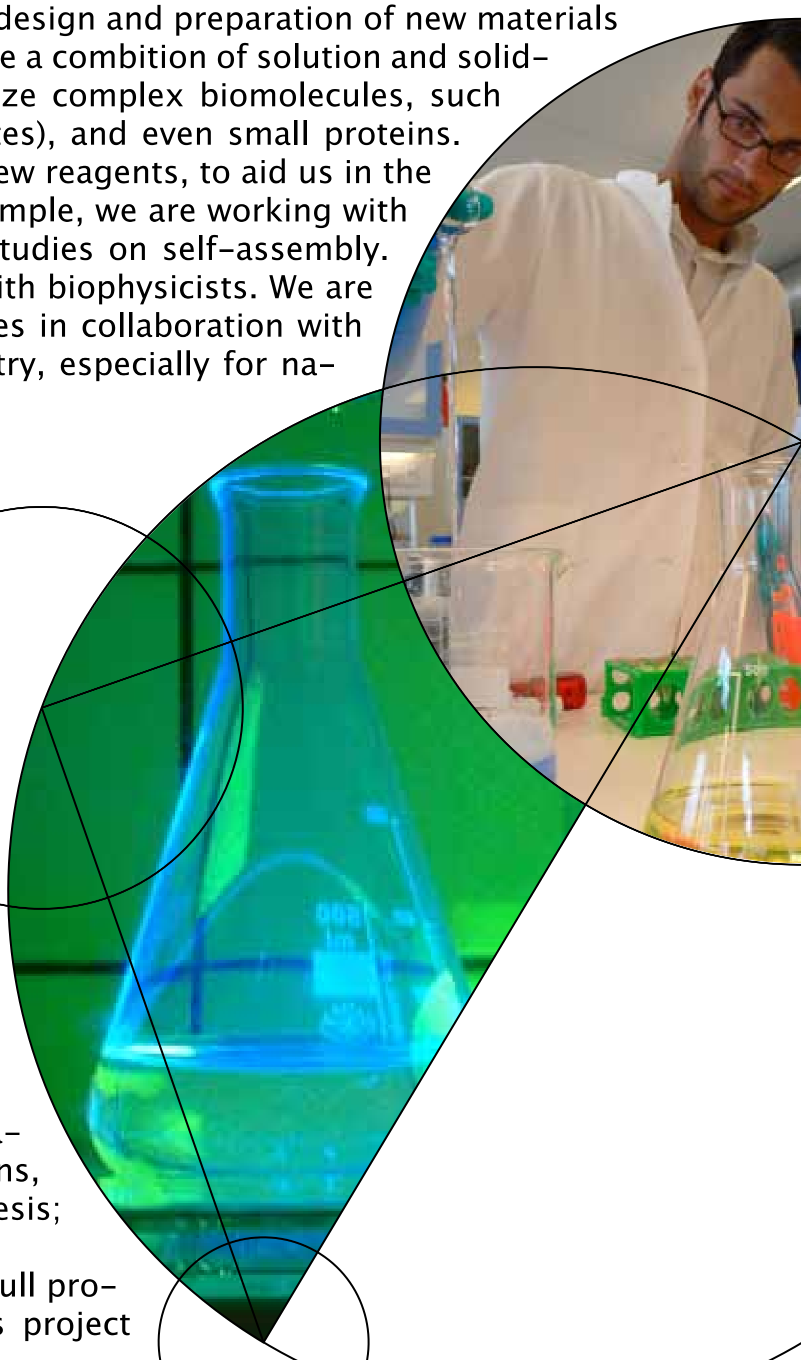
Personnel: 2 full professor, 4 associate professors, 3 Ph.D students, 1 project student.

Contact: Kell Mortensen, kell@life.ku.dk
Lise Arleth, lia@life.ku.dk

NanoBioorganic Chemistry Group

The NanoBioorganic Chemistry group seeks to define and exploit the laws governing self-assembly of biomolecules to build biological meaningful nano-scale structures. The aim is to understand and control the self-assembly of biomolecules in solution and on surfaces. The ability to make defined nano-scale structures of biomolecules leads directly to biomedical applications, including nanomedicine.

Organic synthesis is a powerful tool for the design and preparation of new materials on the Ångstøm and nanometer scale. We use a combition of solution and solid-phase based organic chemistry to synthesize complex biomolecules, such as peptides, glyco-conjugates (carbohydrates), and even small proteins. We also develop new chemistry, including new reagents, to aid us in the synthesis of complex biomolecules. For example, we are working with designer proteins, which we are using in studies on self-assembly. To study these structures, we collaborate with biophysicists. We are using the knowledge gained in these studies in collaboration with partners the from biopharmaceutical industry, especially for nanomedicine.



Techniques: In addition to the classical techniques for chemical synthesis and analysis we use a number of specialized techniques for the synthesis and characterization of biomolecules, including solid-phase synthesis, HPLC, robots for parallel synthesis, microwave reactors, etc. The first characteri¬zation of nanoscale self-assembly is often done in the group but the self-assembled structures are studied in collaborations, for example using small-angle X-ray scattering and STM of self-assembled monolayers.

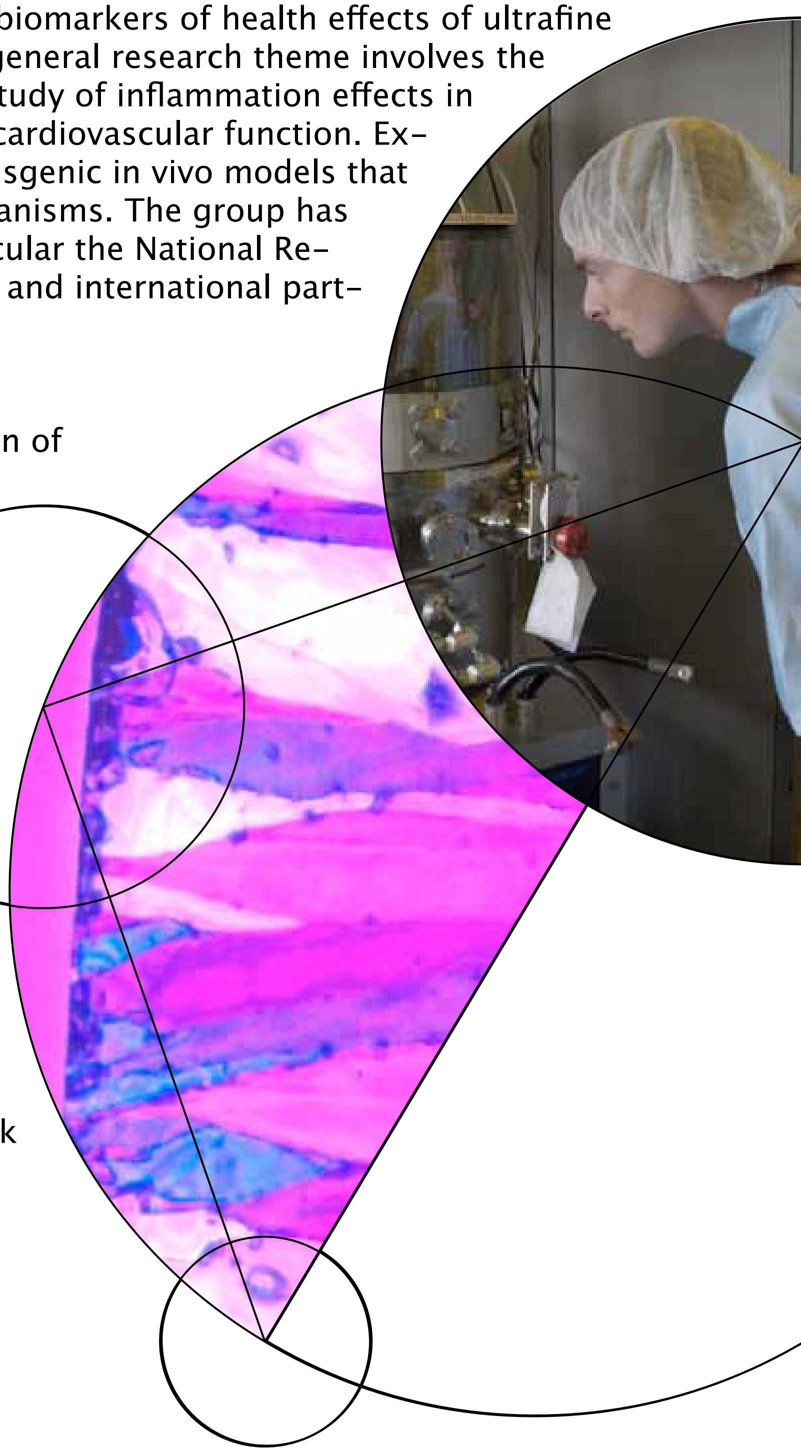
Key Words: Synthetic chemical biology; nanobioscience; synthetic peptides, proteins, and glycans; self-assembly; organic synthesis; nanoparticles; nanomedicine
Personnel: The group currently counts one full professor, 10 PhD's and postdocs, as well as project students.

Contact: Knud J. Jensen, kjj@life.ku.dk

Nanotoxicology

The particle toxicology research group focuses on risk of adverse health effects of nanoparticles. The group belongs to the Department of Environmental Health and is located at the Institute of Public Health, at the Health Sciences Faculty. The department is worldly recognized for its work in the fields of oxidative damage to DNA, experimental study of the effects of nanosized particles, gene expression patterns as biomarkers, reproduction models, personal exposure and biomarkers of health effects of ultrafine and fine particles in human populations. A general research theme involves the generation of reactive oxygen species and study of inflammation effects in terms of DNA damage with cancer risk and cardiovascular function. Experimental studies includes in vitro and transgenic in vivo models that are aimed at explaining the biological mechanisms. The group has strong collaborations with national (in particular the National Research Center for the Working Environment) and international partners, including FP6 and FP7 programs.

Most recent successes include demonstration of vascular effects of exposure to nanoparticles in susceptible animal models and humans only.



Techniques: the group has 350 m2 newly furbished modern laboratories with class 1 and 2 cell culture facilities as well as all molecular biology facilities and analytical chemical equipment such as HPLC and GC/MS. There are excellent (transgenic) animal experimental facilities at the faculty.

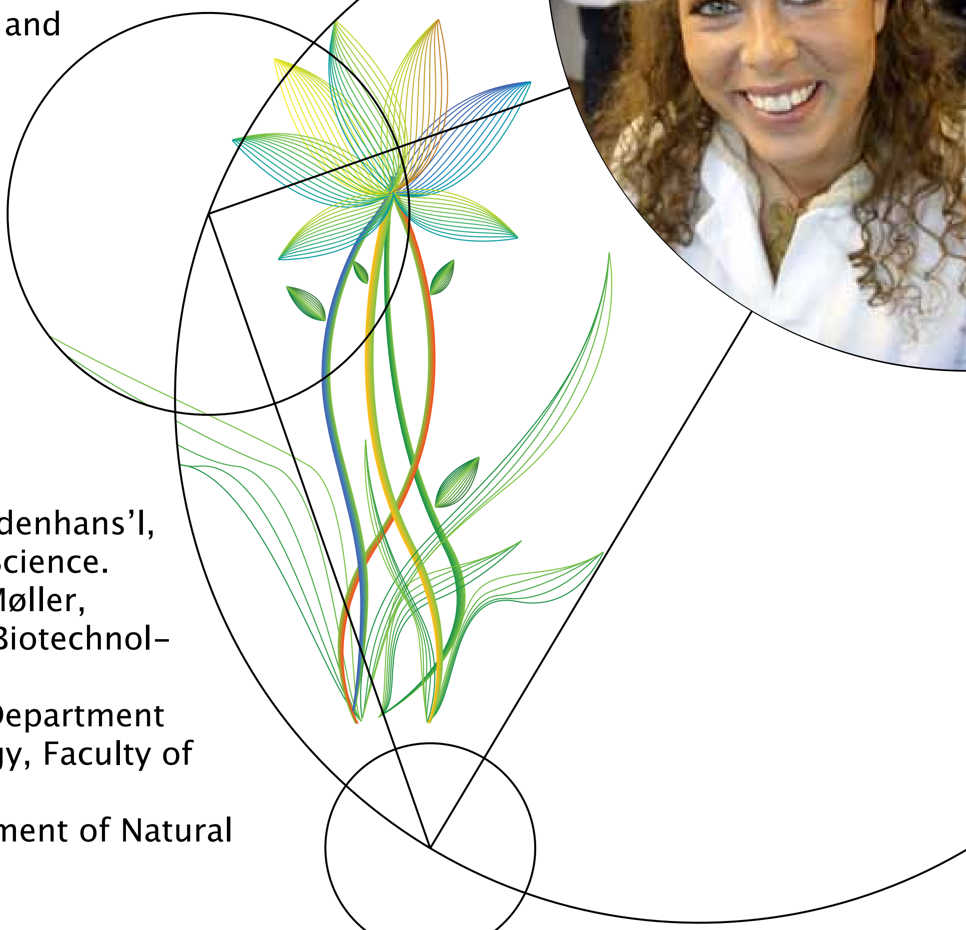
Contact: Steffen Loft, s.loft@pubhealth.ku.dk

NANO-SCIENCE CENTER
UNIVERSITY OF COPENHAGEN

Synthetic Biology

The aim of the research in synthetic biology is to develop and produce artificial biological systems with new tailored properties, for example, for personalised medicine or in relation to sustainable energy. The research will focus on synthetic biology with a starting point in membrane bound proteins, which are the basis for life processes – from photosynthesis to the maintenance of the electrical potential across the cell membrane. In addition to this type of research within synthetic biology, an important part of the project is also to clarify the philosophical and ethical aspects of synthetic biology.

The research area of synthetic biology is established on the basis of an elite grant, UNIK (Investment Capital for University Research) of 120 million kroner from the Danish Ministry of Science, Technology and Innovation. The grant runs from 1. April 2009 – to 31. March 2014. The centre creates a framework for research in synthetic biology within four faculties and gathers researchers and students from more than 7 institutes at the University of Copenhagen. In addition, there is close collaboration with research groups world wide and in particular at University of California, Berkeley, and USA.



Steering group and key investigators
Birger Lindberg Møller is leader of the steering group and the administration of the grant is located in the secretariat for synthetic biology at Faculty of Life Sciences.

Key investigators:
Professor in Chemistry Robert Feidenhans'l, Nano-Science Center, Faculty of Science.
Professor, D.Sc. Birger Lindberg Møller, Department of Plant Biology and Biotechnology, Faculty of Life Sciences.
Professor dr. med. Ulrik Gether, Department of Neuroscience and Pharmacology, Faculty of Health Sciences.
Professor Kell Mortensen, Department of Natural Sciences, Faculty of Life Sciences.

Contact: Birger Lindberg Møller: blm@life.ku.dk