GUELPH-WATERLOO CENTRE FOR GRADUATE WORK IN CHEMISTRY AND BIOCHEMISTRY

(GWC)^2 Website: http://www.gwc2.on.ca

(GWC)^2 Chemistry - Nanotechnology M.Sc./Ph.D. Collaborative Program

Nanotechnology MSc/PhD Collaborative Program

This interdisciplinary research program at the University of Waterloo is the focal point for graduate teaching and research in M.Sc. and Ph.D. programs in Nanotechnology. The program, jointly offered by three departments in the Faculty of Science and four in the Faculty of Engineering, provide students with a stimulating educational environment that spans from basic research through to application. The goal of the collaborative program is to allow students to gain perspectives on nanotechnology from a wide community of scholars within and outside their disciplines in both course and thesis work.

The M.Sc. collaborative program provides a strong foundation in the emerging areas of nano-science in preparation for the workforce or for further graduate study and research leading to a doctoral degree. Four key areas of research strengths have been identified: nanomaterials, nano-electronics design and fabrication, nano-instruments and devices, and nano-biosystems. The objective of the Ph.D. program is to prepare students for careers in academia, industrial R & D and government research labs.

M.Sc. Program

Admission Requirements

M.Sc. students in the collaborative program in nanotechnology must meet the M.Sc. admission requirements of the participating department in which they are enrolled. The minimum academic requirement for admission to the (GWC)^2 M.Sc. program is an honours bachelor's degree (or its equivalent) in Science from a recognized university with a second-class (B) standing. Strong emphasis is also placed on the letters of recommendation received in support of the student's application. Students from foreign countries where English is not the language of instruction are also required to prove their proficiency in English.

Degree Requirements

(GWC)^2 M.Sc. students in the collaborative program in nanotechnology must complete a minimum of 1.5 graduate credits, which must include the following nanotechnology courses; **NANO 701 – Fundamentals of Nanotechnology, NANO 702 – Nanotechnology Tools** and one graduate level Chemistry course from the prescribed list of electives, CHEM 794 (M.Sc. Seminar), and submit and defend an acceptable thesis. NANO 701 and NANO 702 may be waived for students who have completed their BASc degree in Nanotechnology Engineering at the University of Waterloo and will be required to take one half credit (0.5) graduate level Chemistry course from the prescribed list of electives, and two half-credit course from all graduate courses in the prescribed list of electives. Graduate Chemistry students are required to complete CHEM 794 M.Sc. Seminar and are exempted from the Nanotechnology Seminar milestone.

Ph.D. Program

Admission Requirements

Ph.D. students in the collaborative program in nanotechnology must meet the Ph.D. admission requirements of the participating department in which they are enrolled. The minimum academic requirements for the (GWC)^2 normally consists of a Master's degree in Science from a recognized university with a second-class (B) standing. Strong emphasis is also placed on the letters of recommendation received in support of the student's application. Students from foreign countries where English is not the language of instruction are also required to prove their proficiency in English.

Degree Requirements

(GWC)^2 Ph.D. students in the collaborative program in nanotechnology must complete a minimum of 1.5 graduate credits, which must include the following nanotechnology courses; **NANO 701 – Fundamentals of Nanotechnology, NANO 702 – Nanotechnology Tools** and one half credit (0.5) graduate level Chemistry course from the prescribed list of electives, pass an oral comprehensive examination, present a 30-minute seminar, and submit and defend an acceptable thesis. . NANO 701 and NANO 702 may be waived for students who have completed their BASc degree in Nanotechnology Engineering or Masters degree in Nanotechnology at the University of Waterloo and they must complete a minimum of three half

credit (0.5) courses including one half-credit (0.5) graduate level Chemistry course in the prescribed list of electives and two half-credit courses from all graduate courses in the prescribed list of electives. Graduate Chemistry students are required to complete Chem 795 Ph.D. Seminar and are exempted from the Nanotechnology Seminar milestone.

Ph.D. Direct from B.Sc. Program

Admission Requirements

Ph.D. Direct from B.Sc. students in the collaborative program in nanotechnology must meet the Ph.D. admission requirements of the participating department in which they are enrolled. The minimum academic requirements for the (GWC)^2 is possible for outstanding students who graduated with an overall 'A' standing at the undergraduate level. Strong emphasis is also placed on the letters of recommendation received in support of the student's application. Students from foreign countries where English is not the language of instruction are also required to prove their proficiency in English.

Degree Requirements

(GWC)^2 Ph.D. Direct from B.Sc. students in the collaborative program in nanotechnology must complete a minimum of 2.0 graduate credits, which must include the following nanotechnology courses; **NANO 701 – Fundamentals of Nanotechnology, NANO 702 – Nanotechnology Tools,** one half credit (0.5) graduate level Chemistry course and one half credit (0.5) graduate level Chemistry course from the prescribed list of electives, CHEM 794 (M.Sc. Seminar), pass an oral comprehensive examination, present a 30-minute Ph.D. seminar (CHEM 795), and submit and defend an acceptable thesis. NANO 701 and NANO 702 may be waived for students who have completed their BASc degree in Nanotechnology Engineering at the University of Waterloo and they must complete a minimum of four half credit (0.5) courses including one graduate level elective Chemistry course, one half credit (0.5) graduate level Chemistry course from the prescribed list of electives, and two half-credit course from all graduate courses from the prescribed list of electives. Graduate Chemistry students are required to complete Chem 795 Ph.D. Seminar and are exempted from the Nanotechnology Seminar milestone.

Ph.D. Direct from M.Sc. Program

Admission Requirements

Exceptional students currently in the M.Sc. collaborative program in nanotechnology may transfer directly into the Ph.D. program without first completing all of the M.Sc. requirements. The applicant who is applying for direct transfer must have demonstrated a superior academic record both at the undergraduate and graduate level. This will normally mean that the student has a minimum overall B+ average as an undergraduate and has demonstrated a first-class standing with consistently above average performance in at least two graduate courses as well as in the Masters Seminar. The applicant must have already demonstrated an oral and written communication ability appropriate for a Ph.D. level student. In addition, there must be clear evidence of research productivity and promise. Requests for transfer will be considered for approval by the by the Director/Coordinating Committee at the end of the student's third term in the M.Sc. program. I

Degree Requirements

(GWC)^2 Ph.D. Direct from M.Sc. students in the collaborative program in nanotechnology must complete a minimum of 2.5 graduate credits, which must include the following nanotechnology courses; **NANO 701 – Fundamentals of Nanotechnology, NANO 702 – Nanotechnology Tools,** two half credit (0.5) graduate level Chemistry course and one half credit (0.5) graduate level course from the prescribed list of electives, CHEM 794 (M.Sc. Seminar), pass an oral comprehensive examination, present a 30-minute Ph.D. seminar (CHEM 795), and submit and defend an acceptable thesis. NANO 701 and NANO 702 may be waived for students who have completed their BASc degree in Nanotechnology Engineering at the University of Waterloo and they must complete a minimum of five half credit (0.5) courses including two graduate level elective Chemistry course, three half-credit courses from all graduate courses from the prescribed list of electives. Graduate Chemistry students are required to complete Chem 795 Ph.D. Seminar and are exempted from the Nanotechnology Seminar milestone.

Required Nanotechnology Milestone Description

Nanotechnology Seminar

The nanotechnology seminar is a forum for student presentation of research results or proposals. Speakers from academia and industry will also be invited from time to time. The range of topics that will be addressed in the seminar crosses all areas of nanotechnology research in the collaborative program. To receive this milestone credit, the student is required to present at least one seminar.

Note: Graduate Chemistry students are required to complete Chem 794 M.Sc. Seminar and/or Chem 795 Ph.D. Seminar and are exempted from the Nanotechnology Seminar milestone. Seminar attendance requirements can be completed by attendance at any combination of Chemistry and Nanotechnology Seminars.

Required Nanotechnology Core Course Descriptions

Core Courses

Core courses are designed to provide the base knowledge and skill set required to prepare students for more specialized courses and to conduct interdisciplinary nanoscale research. Generally, students are required to take two core courses and complete the Nanotechnology seminar. All core courses will have written examinations.

NANO 701 FUNDAMENTALS OF NANOTECHNOLOGY (0.5)

Students must complete any two of the 0.25 unit weight modules A to F listed below. Each module will typically consist of 18 lecture hours per term.

NANO 701A Nanoscale Surfaces/Interfaces (0.25) LEC

Introduction to the structure and properties of clean and adsorbate-covered surfaces, including metal, semiconductors, oxides and other complex systems. Survey of the physics and chemistry of adsorption, desorption, diffusion, and reorganization phenomena, as well as nanoscale interfacial processes, including capillary phenomena and molecular recognition and self-assembly.

NANO 701B Solid State Physics and Chemistry (0.25) LEC

The purpose of this course is to refresh and deepen concepts pertinent to solid state physics and chemistry, which include chemical bonding in solids, crystal structure, thermal properties of solids, electronic properties of metals (Drude model and free electron model), semiconductors, magnetism, dielectrics, and superconductivity. The course will finish with an introduction to quantum-confined structures and contrast them to the corresponding bulk materials.

NANO 701C Self-assembly Phenomena (0.25) LEC

Introduction to self-assembly, self-assembly in bulk and interfaces, basic concepts and examples. Other self-assembly systems include surfactant system, block co-polymer melt and solutions, DNA's, proteins and lipids and biomimetic systems. Application of self-assembly systems.

NANO 701D Nanoscale Phenomena (0.25) LEC

A general survey of physical, chemical, mechanical, electrical, magnetic, optical and other properties specific to nanoscale objects (generally 1-100 nm); processes and mechanisms contributing to these nanoscale specific properties; examples of recent discoveries; examples of recent applications resulting from these nanoscale phenomena.

NANO 701E Nano-mechanics (0.25) LEC

This module will give an introduction of basic and/or intermediate level theoretical and practical knowledge on classical molecular dynamics, nanomechanics or mechanics of nano-building blocks, (specifically *nanowires, tubes and thin films)*. It mainly focuses on mechanics of atomic arrangements (lattice mechanics), defect analysis (plasticity and elasticity explained by dislocation theory) and stress-strain analysis in nano-building-blocks by electromagnetic radiation and nano-mechanical-tools such as nanoindentor.

NANO 701F Molecular Biophysics (0.25) LEC

Physics perspective on biological phenomena at the molecular scale. Cell structure and molecular composition; intermolecular interactions and hydration; protein structure and function; cytoskeletal filaments; DNA structure and chromosomes; molecular dance, diffusion and biological dynamics (e.g., diffusion to capture); selected topics in nanobiotechnologies.

NANO 702 NANOTECHNOLOGY TOOLS (0.5)

Students must complete any two of the 0.25 unit weight modules A to F listed below. Each module will typically consist of 18 lecture hours per term.

NANO 702A Spectro-microscopy (0.25) LEC

General survey of the basic principles of the common spectroscopies and spectromicroscopies used for nanoscale research, including optical techniques (NMR, FTIR, Raman, UV-Vis, XAS including EXAFS and XANES), electron-based techniques (UPS, XPS, AES), and tip-based techniques (STS); latest development in both lab-based and synchrotron or free electron laser based instrumentation and methods; specific examples of using these techniques to examine nanoscale properties and phenomena.

Recommended: NANO 701A

NANO 702B Nanoscale Fabrication Tools (0.25) LEC

This course module covers the two important elements of nanofabrication: lithography and materials synthesis. An introduction to the established lithography techniques for the nanoscale, namely advanced optical lithography, electron beam lithography and nanoimprint lithography, followed by exploratory tools such as the focused ion beam technique and scanning probe microscopy based lithography. Pattern transfer techniques such as reactive ion etching will also be covered. The focus in materials synthesis will be on thin films. Basics of thin film growth (surfaces and nucleation), epitaxy (mechanisms and nanostructures), growth techniques (chemical vapour deposition, physical vapour deposition) and a review of the fundamental thing film characterization techniques.

NANO 702C Self-assembly Tools (0.25) LEC

Introduction to tools for quantifying self-assembly processes. Scattering techniques include light, x-ray and neutron scattering. Surface characterisation tools, tensiometry, surface plasmon, DPI, ellipsometry. Thermodynamic characterisation tools. Calorimetry. Physical characterization tools – fluorescence spectrometry.

Recommended: NANO 701C

NANO 702D Nanoscale Modeling (0.25) LEC

An overview of continuum and discrete methods used in the modeling of nanoscale systems. Emphasis will be placed on solid structures and fluids under confinements. Models of interactions between atoms, molecules and surfaces will be covered. Analytical and numerical techniques of structural dynamics will be introduced. Tools of molecular simulations such as Molecular Dynamics and Monte Carlo sampling will be discussed. Relevant examples from the recent literature will be presented.

NANO 702E Nanoscale Sensing (0.25) LEC

A general understanding of the concepts of nanotechnology enabled sensors including fundamental theory, functionalization and sensor response. After a brief introduction to the concepts of chemical sensing, fundamentals of various physical transduction platforms (such as capacitive, optical, mechanical, electrochemical, solid state and acoustic wave transducers) will be discussed. The design, fabrication and testing of various inorganic (e.g. nanostructured thin films and mechanical and optical structures) and organic (e.g. surface interaction-, surface modification- and protein-based) nanotechnology enabled sensors for gas, liquid and bio-sensing applications will be presented as case studies. Sensors for electric charge, magnetic field and photons will be discussed.

NANO 702F Microscopy (0.25) LEC

An introduction to high resolution submicron microscopy methods. The course is intended for graduate science and engineering students and will cover optical and fluorescence microscopy; scanning probe microscopy including atomic force microscopy and scanning tunneling microscopy; optical tweezers; electron microscopy, including scanning electron microscopy and transmission electron microscopy.

Nanotechnology Technical Electives

(a) Micro/nano Instruments and Devices

CHEM 750T17 Surface Science and Nanotechnology
CHEM 750TXX Nanostructured Materials and Analysis
CHEM 724 Chemical Instrumentation
ME 770 Topics in Heat and Fluid Flow: Micro- and Nano- fluidics
ME 738 Topics in Materials Science: Materials for NEMS and MEMS
ME 780 Topics in Mechatronics: MEMS Design and Analysis
SyDe 682 Advanced MEMS Physics, Design and Fabrication
SyDe 750 Modeling, Simulation and Design of MEMS
BIOL 642 Current topics in Biotechnology

(b) Nanoelectronics Design and Fabrication

CHEM 750T11 Bioelectronics
ECE 631 Microelectronic Processing Technology
ECE 632 Photovoltaic Energy Conversion
ECE 636 Analog MOS and Bipolar Integrated Circuits
ECE 637 Design of VLSI MOS Integrated Circuits
ECE 672 Optoelectronic Devices
ECE 730T10 Topics in Solid State Devices: Adv. Technology for Semiconductor Processing
ECE 730T13 Topics in Solid State Devices: Nanoelectronics
ECE 730T17 Topics in Solid State Devices: Physics and Modeling of Semiconductor Devices
ECE 730T18 Topics in Solid State Devices: Organic Electronics
ECE 730T19 Topics in Solid State Devices: Magnetism and Spintronics
ECE 730T20 Topics in Solid State Devices: Physics of Nanodevices
ECE 770T11 Topics in Antenna and Microwave Theory: Quantum Info Processing Devices
ECE 770T13 Topics in Antenna and Microwave Theory: Quantum Information Devices
ECE 770T14 Topics in Antenna and Microwave Theory: Quantum Electronics & Photonics
ME 595 Introduction to MEMS Fabrication
ME 596 Topics in Nanotechnology: Introduction to Fabrication & Characterization of Nano-structures
PHYS 713 Molecular Physics
PHYS 731 Solid State Physics
PHYS 747 Optical Electronics

(c) Nano-biosystems

BIOL 608 Advanced Molecular Genetics
BIOL 614 Bioinformatics Tools and Techniques
BIOL 629 Cell Growth and Differentiation
BIOL 642 Current Topics in Biotechnology
CHE 562 Advanced Bioprocess Engineering
CHE 660 Principles of Biochemical Engineering
CHE 661 Advances in Biochemical Engineering
CHE 760 Special Topics in Biochemical Engineering
CHE 765 Research Topics in Biochemical Engineering
CHEM 730 Proteins and Nucleic Acids
CHEM 731T02 Physical Biochemistry
CHEM 737 Enzymes
PHYS 751 Cellular Biophysics
PHYS 752 Molecular Biophysics
BIOL 670 Photobiology
BIOL 678 Current topics in Neurophysiology

(d) Nanomaterials

CHE 541 Introduction to Polymer Science and Properties
CHE 542 Polymerization and Polymer Properties
CHE 612 Interfacial Phenomena
CHE 640 Principles of Polymer Science (Cross-listed with CHEM 770)
CHE 641 Physical Properties of Polymers (Cross-listed with CHEM 771)
CHE 740 Special Topics in Polymer Science and Engineering
CHE 755 Research Topics in Electrochemical Engineering, Interfacial Engineering & Material Science
CHE 745 Research Topics in Polymer Science and Engineering
CHEM 710T12 Structure and Function of Supramolecular Materials
CHEM 710T15 Advanced Solid State Chemistry: Ion, Electron and Molecular Transport
CHEM 710TXX Nanostructured Materials and Integrative Chemistry
CHEM 713 Chemistry of Inorganic Solid State Materials
ME 738 Topics in Materials Science: Materials for NEMS and MEMS
ME 738 Topics in Materials Science: Nanostructured and Amorphous Materials
PHYS 701 Quantum Mechanics
PHYS 704 Statistical Physics
PHYS 706 Electromagnetic Theory
PHYS 773 Special Topics

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Application Information

Application is made through the on-line Ontario University Application Centre (OUAC) through the University of Waterloo:

http://horizon.ouac.on.ca/webapp/account.d2w/report?ident=ACCOUNT_DSP&merchant_rn=656872&action_id=choose