Physics

- **M.Sc. Physics**
- **Ph.D. Physics**
- **M.A.Sc. Biomedical Engineering (listed under Biomedical Engineering** (http://www.carleton.ca/calendars/2012-13/grad/gradprograms/biomedicalengineering) **)**

M.Sc. Physics

About the Program

The fields of graduate study in the Department of Physics at Carleton are particle physics and medical physics. Both the M.Sc. and the Ph.D. are available in each.

In the particle physics program, specialization can be in theoretical or in experimental particle physics.

In the medical physics program, specialization can be in imaging physics, cancer therapy physics, or medical biophysics. Research supervision can be on campus or be provided at health care institutions and government laboratories in the Ottawa region. The M.Sc. program leads to our CAMPEP-accredited Ph.D. program (**campep.org**)

The graduate program in physics is a joint program with the University of Ottawa as part of the Ottawa Carleton Institute for Physics (OCIP).

The fields of study offered by OCIP at the University of Ottawa are condensed matter physics, biological physics, and photonics.

Detailed information about our research program is available from the departmental website.

Academic Regulations

See the General Regulations (http://www.carleton.ca/calendars/2012-13/grad/gradregulations) section of this Calendar.

Admission Requirements

An Honours B.Sc. in Physics or a closely related field at a standard acceptable to the two universities is normally required for admission to the M.Sc. program.

The admissions committee may require students to take an orientation examination during the first weeks of residence. The results of this examination may indicate the need for a student to register in undergraduate courses to fill gaps in his/her knowledge.

It is strongly recommended that all students have had at least one course in computing.

Candidates admitted to the M.Sc. program with more than the minimum course requirements may be permitted to credit towards the degree a maximum of 1.0 credit at the senior undergraduate level. This maximum does not apply to qualifying-year students.

Program Requirements

M.Sc. with Thesis

- 2.5 credits of course work
- A thesis (2.5 credits) defended at an oral examination
- Participation in the seminar series of the Ottawa-Carleton Institute for Physics

Students with academic preparation particularly well suited for their chosen field of study may have their course credit requirements reduced to 2.0 credits. In this case, a 3.0-credit thesis will be required.

The minimum number of courses is 1.5 credits. At least 1.0 credit must consist of lecture courses at the graduate level. The courses PHYS 5900 [1.0] and PHYS 5901 are courses on Selected Topics, normally given as directed studies, and cannot fulfill this lecture course requirement. Most students will be expected to take PHYS 5002, or another equivalent computing physics course. Students in experimental or theoretical particle physics streams will normally include the following among their courses:

PHYS 5601 [0.5]	Experimental Techniques of Nuclear and Elementary Particle Physics
PHYS 5602 [0.5]	Physics of Elementary Particles
PHYS 5701 [0.5]	Intermediate Quantum Mechanics with Applications
PHYS 5702 [0.5]	Relativistic Quantum Mechanics

Medical Physics Stream

The three areas of specialization are:

1. imaging
2. therapy
3. biophysics

All students are required to take the following:

PHYS 5203 [0.5]	Medical Radiation Physics
0.5 credit appropriate physics course from an area of physics other than medical physics. In addition:	
For imaging:	
PHYS 5204 [0.5]	Physics of Medical Imaging (required)
For therapy:	
PHYS 5206 [0.5]	Medical Radiotherapy Physics (required)
For biophysics, 0.5 credit chosen from:	
PHYS 5207 [0.5]	Radiobiology (required)
Cell Biology	
Physiology	
Anatomy	

Students with a medical/health physics background may have the selection of required courses adjusted to reflect their preparation and may receive advanced standing for equivalent courses.

A selection from PHYS 5208, PHYS 5209, or, (with approval) other appropriate courses in physics, engineering, computer science, business or law can be used to complete the program.

In special cases, the requirements may also be met by taking 5.0 credits of course work. 1.0 credit must be the selected topics course PHYS 5900 [1.0].

Physics in modern technology stream

3.0 credits of course work

PHYS 5905 [1.0]	Physics in Modern Technology Work Term
Students will normally include two among their courses:	
PHYS 5002 [0.5]	Computational Physics
PHYJ 5003 [0.5]	Computer Simulations in Physics
PHYJ 5004 [0.5]	Computational Physics I
PHYJ 5005 [0.5]	Computational Physics II

Students enrolled in the physics in modern technology stream are required to complete a work term rather than a research thesis. Students in this stream who wish to pursue a research degree should consult with the graduate supervisor. Although every effort is made to find a work term position for every student enrolled in the physics in modern technology stream, no guarantee of employment can be made. To minimize the likelihood of a work term position not being found, enrollment will be limited to reflect the availability of work term placements. In the event that a work term placement cannot be found, students may fulfill the M.Sc. requirements with courses only as described above.

Guidelines for Completion of Master's Degree

With the exception of those students in the physics in modern technology stream, full-time master's candidates are expected to complete all requirements in six terms of registered full-time study. Part-time master's candidates are expected to complete their degree requirements within an elapsed period of three to four calendar years after the date of initial registration.

Students in the physics in modern technology stream are normally expected to complete all their requirements in three successive terms of registered full-time study.

Residence Requirement

At least one year of full-time study (or equivalent).

Ph.D. Physics

About the Program

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In the particle physics program, specialization can be in theoretical or in experimental particle physics.

In the medical physics program, specialization can be in imaging physics, cancer therapy physics, or medical biophysics. Research supervision can be on campus or be provided at health care institutions and government laboratories in the Ottawa region. The Ph.D. program is accredited by CAMPEP (**campep.org**).

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The fields of study offered by OCIP at the University of Ottawa are condensed matter physics, biological physics, and photonics.

Detailed information about our research program is available from the departmental website.

Academic Regulations

See the General Regulations (http://www.carleton.ca/calendars/2012-13/grad/gradregulations) section of this Calendar.

Admission Requirements

An M.Sc. in Physics, or a closely related field, is normally required for admission into the Ph.D. program.

Students who have been admitted to the M.Sc. program may be permitted to transfer into the Ph.D. program if they demonstrate academic abilities for advanced research in their field.

In exceptional cases, an outstanding student who has completed the honours B.Sc. will also be considered.

Program Requirements (from M.Sc.)

The normal requirements for the Ph.D. degree (after M.Sc.) are

- A minimum of 2.0 credits of course work at the graduate level
- A comprehensive examination designed to demonstrate overall ability in physics and in the candidate's research area, normally within the first year of study. This takes the form of a written examination followed, if necessary, by an oral examination.
- Participation in the seminar series of the Ottawa-Carleton Institute for Physics.
- A thesis (8.0 credits) which will be defended at an oral examination. The examining board for all theses will include members of the Ottawa-Carleton Institute for Physics from both Departments of Physics. The external examiner of the thesis will be external to both Departments of Physics.
- Students in experimental or theoretical particle physics who lack any of the relevant courses recommended for the M.Sc. program must complete them (or the equivalents) by the end of their Ph.D. program. In addition they should complete PHYS 6601 and PHYS 6602
- Students in medical physics must have completed, either within this degree (as part of the minimum 2.0 course credits) or in prior graduate studies:

PHYS 5203 [0.5]	Medical Radiation Physics (or equivalent)
PHYS 5204 [0.5]	Physics of Medical Imaging (or equivalent)
PHYS 5206 [0.5]	Medical Radiotherapy Physics (or equivalent)
PHYS 5207 [0.5]	Radiobiology (or equivalent)
PHYS 5209 [0.5]	Medical Physics Practicum (or equivalent)

PHYS 5210 [0.0]	Anatomy and Physiology for Medical Physicists (or equivalent)

0.5 credit appropriate physics course from an area of physics outside medical physics

In addition it is also strongly recommended to have completed 0.5 credit in a computational physics course, such as PHYS 5002, within the minimum 2.0 credits of this degree or in prior graduate studies.

Guidelines for Completion of Doctoral Degree

Full-time Ph.D. candidates admitted on the basis of an M.Sc. are expected to complete all requirements within an elapsed period of four to five years after the date of initial registration. Part-time Ph.D. candidates are expected to complete all requirements within an elapsed period of six years after the date of initial registration.

Residence Requirements

For the Ph.D. degree (from B.Sc.): at least three years of full-time study (or equivalent).

For the Ph.D. degree (from M.Sc.): at least two years of full-time study (or equivalent).

Physics (PHYS) Courses

PHYS 5002 [0.5 credit] (PHY 5344)
Computational Physics
Computational methods used in analysis of experimental data. Introduction to probability and random variables. Monte Carlo methods for simulation of random processes. Statistical methods for parameter estimation and hypothesis tests. Confidence intervals. Multivariate data classification. Unfolding methods. Examples taken primarily from particle and medical physics.
Prerequisite(s): an ability to program in FORTRAN, Java, C, or C++ or permission of the Department.
Also offered at the undergraduate level, with different requirements, as PHYS 4807, for which additional credit is precluded.

PHYS 5101 [0.5 credit] (PHY 8111)
Classical Mechanics and Theory of Fields
Hamilton's principle; conservation laws; canonical transformations; Hamilton-Jacobi theory; Lagrangian formulation of classical field theory.
Prerequisite(s): permission of the Department.

PHYS 5201 [0.5 credit]
Introduction to Medical Imaging Principles and Technology
Basic principles and technological implementation of x-ray, nuclear medicine, magnetic resonance imaging (MRI), and other imaging modalities used in medicine. Contrast, resolution, storage requirements for digital images. Applications outside of medicine, future trends.
Precludes additional credit for BIOM 5201.
Prerequisite(s): permission of the Physics Department.

PHYS 5202 [0.5 credit] (PHY 8122)
Special Topics in Molecular Spectroscopy
Topics may include: electronic spectra of diatomic and triatomic molecules and their interpretation using molecular orbital diagrams; Raman and resonance Raman spectroscopy; symmetry aspects of vibrational and electronic levels of ions and molecules in solids; the presence of weak and strong resonant laser radiation.
Also listed as CHEM 5009/CHM 8150.
Prerequisite(s): permission of the Department.

PHYS 5203 [0.5 credit] (PHY 5161)
Medical Radiation Physics
Interaction of electromagnetic radiation with matter. Sources: X-ray, accelerators, radionuclide. Charged particle interaction mechanisms, stopping powers, kerma, dose. Introduction to dosimetry. Units, measurements, dosimetry devices.
Prerequisite(s): permission of the Department.

PHYS 5204 [0.5 credit] (PHY 5112)
Physics of Medical Imaging
Physical foundation of and recent developments in transmission X-ray imaging, computerized tomography, nuclear medicine, magnetic resonance imaging, and ultrasound, for the specialist imaging physicist. Image quality, contrast, resolution, SNR, MTF, DQE. Introduction to image processing, system performance assessment.
Prerequisite(s): PHYS 5203 and PHYS 4203, or permission of the Department.

PHYS 5206 [0.5 credit] (PHY 5164)
Medical Radiotherapy Physics
Radiation therapy process and physics. Ion chamber dosimetry, Monte Carlo techniques of radiation transport, cavity theories, external beam therapy, brachytherapy, dosimetry protocols, detectors used in radiation therapy. Treatment planning, monitor unit calculations, intensity-modulated radiation therapy. Novel and alternate techniques.
Prerequisite(s): PHYS 5203 or permission of the Department.

PHYS 5207 [0.5 credit] (PHY 5165)
Radiobiology
Physics and chemistry of radiation interactions. Cell biology, DNA damage and repair, survival curves and models, radiosensitivity, oxygen effect. Linear energy transfer, relative biological effectiveness. Whole body radiation effects, radioprotectors, radiosensitizers. Hyperthermia. Molecular techniques in radiobiology. Model tumour systems.
Prerequisite(s): PHYS 5203 must have been taken, or be taken concurrently, or permission of the Department.

PHYS 5208 [0.5 credit] (PHY 5163)
Radiation Protection
Dose quantities, effects of radiation exposure, fetal risks, scientific basis for protection, dose limits. Background radiation, dose from internal radionuclides. Doses in radiology, incidents in radiation therapy. Shielding design, working with radioactive materials. Instruments and measurement. Radiation protection organizations.
Prerequisite(s): PHYS 5203 or permission of the Department.

PHYS 5209 [0.5 credit] (PHY 5166)
Medical Physics Practicum
Experience with current clinical medical imaging and cancer therapy equipment, and dosimetry and biophysics instrumentation. The course requires completion of experimental projects on medical imaging, radiotherapy, dosimetry, and biophysics, conducted at local clinics and NRC laboratories.
Prerequisite(s): PHYS 5203. Also, as appropriate to the majority of projects undertaken, one of PHYS 5204, PHYS 5206, PHYS 5207, or other biophysics course, or permission of the Department.

PHYS 5210 [0.0 credit] (PHY 5168)
Anatomy and Physiology for Medical Physicists
An overview of human anatomy and physiology as background for the application of physics to cancer therapy and medical imaging. Anatomy as depicted by imaging technologies such as CT, mri, and radiography will be emphasized. Graded Sat/Uns.
Prerequisite(s): enrollment in the graduate program in medical physics or permission of the Department.

PHYS 5291 [0.5 credit] (PHY 5167)
Advanced Topics in Medical Physics
Topics may include medical imaging physics, cancer therapy physics, medical biophysics, or radiation protection and health physics.
Prerequisite(s): PHYS 5203 plus, as appropriate to the particular advanced topic offered, at least one of PHYS 5204, PHYS 5206, PHYS 5207; or permission of the Department.

PHYS 5302 [0.5 credit] (PHY 8132)
Classical Electrodynamics
Covariant formulation of electrodynamics; Lenard-Wiechert potentials; radiation reaction; plasma physics; dispersion relations.
Prerequisite(s): PHYS 4307 or equivalent, or permission of the Department.

PHYS 5318 [0.5 credit] (PHY 5318)
Modern Optics
Electromagnetic wave propagation; reflection, refraction; Gaussian beams; guided waves. Laser theory: stimulated emission, cavity optics, gain and bandwidth, atomic and molecular lasers. Mode locking, Q switching. Diffraction theory, coherence, Fourier optics, holography, laser applications. Optical communication systems, nonlinear effects: devices, fibre sensors, integrated optics.
Prerequisite(s): permission of the Department.
Also offered at the undergraduate level, with different requirements, as PHYS 4208, for which additional credit is precluded.

PHYS 5601 [0.5 credit] (PHY 5966)
Experimental Techniques of Nuclear and Elementary Particle Physics
The interaction of radiation and high energy particles with matter; experimental methods of detection and acceleration of particles; use of relativistic kinematics; counting statistics.
Prerequisite(s): PHYS 4307 or equivalent, and PHYS 4707; or permission of the Department.

PHYS 5602 [0.5 credit] (PHY 5967)
Physics of Elementary Particles
Properties of leptons, quarks, and hadrons. The fundamental interactions. Conservation laws; invariance principles and quantum numbers. Resonances observed in hadron-hadron interactions. Three body phase space. Dalitz plot. Quark model of hadrons, mass formulae. Weak interactions; parity violation, decay of neutral kaons; CP violation; Cabibbo theory.
Prerequisite(s): PHYS 4707 or permission of the Department.
Also offered at the undergraduate level, with different requirements, as PHYS 4602, for which additional credit is precluded.

PHYS 5604 [0.5 credit] (PHY 8164)
Intermediate Nuclear Physics
Properties of the deuteron and the neutron-proton force. Nucleon-nucleon forces, isospin and charge independence. Nuclear models. Scattering theory. Interpretation of n-p and p-p scattering experiments. Interaction of nucleons with electrons. Interaction of nuclei with radiation.
Prerequisite(s): PHYS 4608 or permission of the Department.

PHYS 5701 [0.5 credit] (PHY 5170)
Intermediate Quantum Mechanics with Applications
Angular momentum and rotation operations; Wigner and Racah coefficients; several and many electron problem in atoms; variational and Hartree-Fock formalism; introduction to second quantized field theory; scattering theory.
Prerequisite(s): PHYS 4707 and PHYS 4708 or permission of the Department.

PHYS 5702 [0.5 credit] (PHY 8172)
Relativistic Quantum Mechanics
Relativistic wave equations. Expansion of S matrix in Feynman perturbation series. Feynman rules. An introduction to quantum electro-dynamics with some second quantization. Gauge theories. May include introduction to Standard Model.
Prerequisite(s): PHYS 5701 and permission of the Department.

PHYS 5801 [0.5 credit] (PHY 5140)
Methods of Theoretical Physics I
This course and PHYS 5802 are designed for students who wish to acquire a wide background of mathematical techniques. Topics can include complex variables, evaluation of integrals, approximation techniques, dispersion relations, Pade approximants, boundary value problems, Green's functions, integral equations.

PHYS 5802 [0.5 credit] (PHY 5141)
Methods of Theoretical Physics II
This course complements PHYS 5801.Topics include group theory, discussion of SU2, SU3, and other symmetry groups. Lorentz group.

PHYS 5900 [1.0 credit] (PHY 8290)
Selected Topics in Physics (M.Sc.)
A student may, with the permission of the Department, take more than one selected topic, in which case each full course is counted for credit.
Prerequisite(s): permission of the Department.

PHYS 5901 [0.5 credit] (PHY 8191)
Selected Topics in Physics (M.Sc.)
Prerequisite: permission of the Department.

PHYS 5905 [1.0 credit] (PHY 5495)
Physics in Modern Technology Work Term
Experience for students enrolled in the physics in modern technology stream. To receive course credit, students must receive satisfactory evaluations for their work term employment. Written and oral reports describing the work term project are required.
Prerequisite(s): Registration in the physics in modern technology stream of the M.Sc. program and permission of the Department.

PHYS 5909 [2.5 credits] (PHY 7999)
M.Sc. Thesis
Prerequisite: permission of the Department.

PHYS 6601 [0.5 credit] (PHY 8165)
Particle Physics Phenomenology
This course covers much of the required knowledge for research in particle physics from both the experimental and theoretical points of view. Topics may include: standard model, parton model, quark model, hadron spectroscopy, and tests of QCD.
Prerequisite(s): PHYS 5602 or permission of the Department.

PHYS 6602 [0.5 credit] (PHY 8166)
Advanced Topics in Particle Physics
Phenomenology. This course will consist of a variety of seminars and short lecture courses, and will cover topics of immediate interest to the research program of the department.
Prerequisite(s): PHYS 6601 or permission of the Department.

PHYS 6701 [0.5 credit] (PHY 8173)
Quantum Field Theory
Relativistic quantum field theory; second quantization of Bose and Fermi fields; reduction and LSZ formalism; perturbation expansion and proof of renormalizability of quantum field theories; calculations of radiative corrections and applications.
Prerequisite(s): PHYS 5701 and PHYS 5702, or permission of the Department.

PHYS 6900 [0.5 credit] (PHY 8490)
Selected Topics in Physics (Ph.D.)
Prerequisite: permission of the Department.

PHYS 6901 [0.5 credit] (PHY 8391)
Selected Topics in Physics (Ph.D.)
Prerequisite: permission of the Department.

PHYS 6909 [8.0 credits] (PHY 9999)
Ph.D. Thesis
Prerequisite: permission of the Department.

Summer session: some of the courses listed in this Calendar are offered during the summer. Hours and scheduling for summer session courses will differ significantly from those reported in the fall/winter Calendar. To determine the scheduling and hours for summer session classes, consult the class schedule at central.carleton.ca

Not all courses listed are offered in a given year. For an up-to-date statement of course offerings for the current session and to determine the term of offering, consult the class schedule at central.carleton.ca