Physics

This section presents the requirements for programs in:

- M.Sc. Physics - Particle Physics Stream
- M.Sc. Physics - Medical Physics Stream
- M.Sc. Physics - Physics in Modern Technology Stream
- M.Sc. Physics Medical Physics Stream with Specialization in Data Science
- M.Sc. Physics Particle Physics Stream with Specialization in Data Science
- Ph.D. Physics

Program Requirements

M.Sc. Physics - Particle Physics Stream (5.0 credits):

Requirements - Particle Physics Stream:

1. 2.0 credits in:		2.0
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	
2. 0.5 credit in:		0.5
PHYS 5002 [0.5]	Computational Physics (or equivalent course in computing physics)	
3. 2.5 credits in:		2.5
PHYS 5909 [2.5]	M.Sc. Thesis (defended at an oral examination)	
4. Participation in the seminar series of the Ottawa-Carleton Institute of Physics		
Total Credits		5.0

Notes:

1. Of the 2.5 credits of course work, no more than 1.5 credits may be fulfilled by Selected Topics such as PHYS 5900 [1.0], PHYS 5901 [0.5]. 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

M.Sc. Physics - Medical Physics Stream (5.0 credits):

Requirements - Medical Physics Stream:

1. 0.5 credit in:		0.5
PHYS 5203 [0.5]	Medical Radiation Physics	
2. 0.5 credit in:		0.5
PHYS 5002 [0.5]	Computational Physics (or equivalent course in computing physics)	
3. 0.5 credit from:		0.5
PHYS 5204 [0.5]	Physics of Medical Imaging (for imaging)	
PHYS 5206 [0.5]	Medical Radiotherapy Physics (for therapy)	
PHYS 5207 [0.5]	Radiobiology (for biophysics. Alternately, course in Cell Biology, Physiology, Anatomy may be chosen)	
4. 0.5 credit in PHYS or PHYJ from an area of physics other than medical physics		0.5
5. 0.5 additional credit in PHYS or PHYJ		0.5
6. 2.5 credits in:		2.5
PHYS 5909 [2.5]	M.Sc. Thesis (defended at an oral examination)	
7. Participation in the seminar series of the Ottawa-Carleton Institute for Physics		
Total Credits		5.0

Notes:

1. A selection from PHYS 5208 [0.5], PHYS 5209 [0.5], or, (with approval) other appropriate courses in physics, engineering, computer science, business or law can be used to complete the program.
2. Of the 2.5 credits of course work, no more than 1.5 credits may be fulfilled by Selected Topics such as PHYS 5900 [1.0], PHYS 5901 [0.5]. 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].

M.Sc. Physics - Physics in Modern Technology Stream (4.0 credits):

Requirements - Physics in Modern Technology Stream:

1. 1.0 credit from:		1.0
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	
2. 2.0 additional credits in PHYS or PHYJ		2.0
3. 1.0 credit in:		1.0
PHYS 5905 [1.0]	Physics in Modern Technology Work Term	
Total Credits		4.0

Note:

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 4.0 credits of course work.

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.

M.Sc. Physics
Medical Physics Stream with Specialization in Data Science (5.0 credits)

Requirements:

1. 0.5 credit in:		0.5
DATA 5000 [0.5]	Data Science Seminar	
2. 0.5 credit in:		0.5
PHYS 5002 [0.5]	Computational Physics (or equivalent course in computing physics)	
3. 0.5 credit in:		0.5
PHYS 5203 [0.5]	Medical Radiation Physics	
4. 0.5 credits from:		0.5
PHYS 5204 [0.5]	Physics of Medical Imaging (for imaging)	
PHYS 5206 [0.5]	Medical Radiotherapy Physics (for therapy)	
PHYS 5207 [0.5]	Radiobiology (for biophysics)	
5. 0.5 additional credit in PHYS or PHYJ. With approval, an appropriate graduate-level course in engineering, computer science, business or law can be used.		0.5
6. 2.5 credits in		2.5
PHYS 5909 [2.5]	M.Sc. Thesis (on a data science topic approved by the Data Science governance committee and defended at an oral examination)	
7. Participation in the seminar series of the Ottawa-Carleton Institute for Physics		
Total Credits		5.0

M.Sc. Physics
Particle Physics Stream with Specialization in Data Science (5.0 credits)

Requirements:

1. 0.5 credit in:		0.5
DATA 5000 [0.5]	Data Science Seminar	
2. 0.5 credit in:		0.5
PHYS 5002 [0.5]	Computational Physics (or equivalent course in computing physics)	
3. 1.5 credit in:		1.5
PHYS 5602 [0.5]	Physics of Elementary Particles	
PHYS 5701 [0.5]	Intermediate Quantum Mechanics with Applications	
PHYS 5702 [0.5]	Relativistic Quantum Mechanics	
4. 2.5 credits in:		2.5
PHYS 5909 [2.5]	M.Sc. Thesis (on a data science topic approved by the Data Science governance committee and defended at an oral examination)	
5. Participation in the seminar series of the Ottawa-Carleton Institute of Physics		
Total Credits		5.0

Ph.D. Physics (10.0 credits)

Requirements:

1. 2.0 credits course work at the graduate level		2.0
2. 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		
3. Participation in the seminar series of the Ottawa-Carleton Institute for Physics		
4. 8.0 credits in:		8.0
PHYS 6909 [8.0]	Ph.D. Thesis (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.)	
Total Credits		10.0

Notes

- 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 Practical Measurements (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.
  - Irrespective of courses taken previously at another institution, students may be required to complete one or more of PHYS 5204, PHYS 5206, or PHYS 5207 as preparation for their thesis research.

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).

Admission

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.

For the M.Sc. Physics – Medical Physics Stream, 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.

Accelerated Pathway

The accelerated pathway in the Department of Physics is a flexible and individualized plan of graduate study. Students in their final year of a Carleton B.Sc. Honours degree in Physics with demonstrated excellent aptitude for research may qualify for this option.

Students in their third-year of study in the B.Sc. Honours degree in Physics should consult with both the Undergraduate Advisor and the Graduate Advisor to determine if the accelerated pathway is appropriate for them and to confirm their selection of courses and Honours project supervisor for their final year of undergraduate studies.

Particle physics accelerated pathway: students must complete PHYS 5002 Computational Physics and PHYS 5602 Physics of Elementary Particles with a grade of B+ or higher in each.

Medical physics accelerated pathway: students must complete PHYS 5002 Computational Physics and PHYS 5313 Physical Applications of Fourier Analysis with a grade of B+ or higher in each.

Students may receive advanced standing with transfer of credit of up to 1.0 credit which will reduce their time to completion.

Admission

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 be considered.

Physics (PHYS) Courses

With the exception of PHYS 5701 Intermediate Quantum Mechanics with Applications and PHYS 5302 Classical Electrodynamics, which may be offered at either Carleton or the University of Ottawa, all PHYS courses are offered only at Carleton, and all PHYJ courses are offered only at the University of Ottawa.

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.
Includes: Experiential Learning Activity
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.
Includes: Experiential Learning Activity
Prerequisite(s): PHYS 5203 and one of PHYS 4203 or PHYS 5313, 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.
Includes: Experiential Learning Activity
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.
Includes: Experiential Learning Activity
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.
Includes: Experiential Learning Activity
Prerequisite(s): PHYS 5203 or permission of the Department.

PHYS 5209 [0.5 credit] (PHY 5166)
Medical Physics Practical Measurements
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.
Includes: Experiential Learning Activity
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; Liénard-Wiechert potentials; radiation reaction; plasma physics; dispersion relations.
Prerequisite(s): PHYS 3308, PHYS 3802, and PHYS 3807, or equivalent courses, or permission of the Department.

PHYS 5313 [0.5 credit]
Physical Applications of Fourier Analysis
Fourier transform, convolution. Sampling theorem. Applications to imaging: descriptors of spatial resolution, filtering. Correlation, noise power. Discrete Fourier transform, FFT. Filtering of noisy signals. Image reconstruction in computed tomography and magnetic resonance. Laplace transform. Integral transforms, application to boundary value problems.
Also listed as PHYS 4203.
Lectures three hours a week.

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 5401 [0.5 credit]
Astrophysics
Stellar evolution, including stellar modeling, main sequence stars, red giants and the end states of stars such as neutron stars and black holes. Galactic structure and dynamics. Neutrino astrophysics.
Also offered at the undergraduate level, with different requirements, as PHYS 4201, 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.
Includes: Experiential Learning Activity
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 5804 [0.5 credit]
Introduction to General Relativity
Special relativity using tensor analysis. Curved spacetime with physics applications which may include the solar system, stars, black holes, and gravitational waves. Introduction to differential geometry and Einstein’s field equations.
Also offered at the undergraduate level, with different requirements, as PHYS 4804., for which additional credit is precluded.

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(s): 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.
Includes: Experiential Learning Activity
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
Includes: Experiential Learning Activity
Prerequisite(s): 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.
Includes: Experiential Learning Activity
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.
Includes: Experiential Learning Activity
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(s): permission of the Department.

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

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