Ottawa-Carleton Institute for Physics

Herzberg Bldg. 316

The Institute

Director of the Institute:
Brian Hird
Associate Director:
Patricia Kalyniak

Students wishing to pursue studies in physics at the M.Sc. and Ph.D. levels in the Ottawa area do so in a cooperative program that combines the resources of the Departments of Physics of Carleton University and the University of Ottawa. The two universities have a joint committee supervising the programs, regulations and student admissions.

Students are admitted for graduate work under the general regulations of the institute, which include criteria related to academic performance, research experience and referees' appraisals. The choice of program and/or research project and supervisor will determine the primary campus location of the student. The student's advisory committee will normally include faculty members from both universities.

The areas of physics available for programs leading to the M.Sc. or the Ph.D. degree include high energy and medical physics (Carleton), condensed matter and surface physics (Ottawa) and theoretical and nuclear physics (both campuses).

Particularly for the medical physics program, research supervision may be provided by members of other institutions in the area such as hospitals, cancer clinics and government laboratories. The list below of all members of the institute along with their research interests can be used as a guide to possible supervisors.

Requests for information and completed applications should be sent to the director of the institute.

Members of the Institute

J.C. Armitage, *High energy physics, instrumentation*
R.K. Carnegie, *Experimental high energy physics*
A.L. Carter, *Intermediate energy physics, instrumentation*
Sylvain Charbonneau, *Semiconductor physics*
R.L. Clarke, *Medical physics*
L.A. Copley, *Theoretical particle physics*
Joanna Cygler, *Medical physics*
Suhit Das, *Semiconductor physics*
Serge Desgreniers, *High pressure physics*
Marie D'Iorio, *Condensed matter*
Madhu Dixit, *Experimental high energy physics*
K.W. Edwards, *Experimental high energy physics*
P.G. Estabrooks, *Experimental high energy physics*
Emery Fortin, *Semiconductor physics*
L.H. Gerig, *Medical physics*
Stephen Godfrey,*Theoretical particle physics*
Francis Guillon, *Condensed matter*
J.E. Hardy, *Field theory*
C.K. Hargrove, *Experimental high energy physics*
Jacques Hebert, *High energy physics*
R.J. Hemingway, *Experimental high energy physics*
Gerhart Herzberg, *Atomic spectroscopy*
Brian Hird, *Ion physics*
R.J.W. Hodgson, *Theoretical nuclear physics*
B.J. Jarosz, *Medical physics*
Paul Johns, *Medical physics*
Bela Joos, *Theoretical condensed matter*
Patricia Kalyniak, *Theoretical particle physics*
Dean Karlen, *Experimental high energy physics*
Dan Kessler, *Astrophysics*
Gilles Lamarche, *Low temperature physics*
M.A.R. LeBlanc, *Superconductivity*
Ivan L'Heureux, *Nonequilibrium processes*
B.A. Logan, *Nuclear physics*
Michael Losty, *Experimental high energy physics*
M. Marchand, *Condensed matter physics*
Paul Marmet, *Atomic and molecular physics*
H.J.A.F. Mes, *Experimental high energy physics*
Gerald Oakham, *Experimental high energy physics*
Michael Ogg, *Experimental high energy physics*
P. Piercy, *Condensed matter physics*
G.P. Raaphorst, *Medical physics*
Denis Rancourt, *Solid state magnetism*
Lazer Resnick, *Theoretical particle physics*
D.W.O. Rogers, *Medical physics*
W.J. Romo, *Theoretical nuclear and particle physics*
Alain Roth, *Condensed matter*
J.K. Saunders, *Medical physics*
David Sinclair, *Solar neutrino physics*
Gary Slater, *Polymer physics*
A.K.S. Song, *Theoretical studies in solid state*
Zbigniew Stadnik, *Electronic structure and magnetism*
M.K. Sundaresan, *Theoretical particle physics*
Roger Taylor, *Condensed matter theory*
Y.P. Varshni, *Theoretical solid state, astrophysics*
P.J.S. Watson, *Theoretical particle physics*
Digby Williams, *Condensed matter*
James Webb, *Condensed matter*
J.C. Woolley, *Semiconductor physics*

Master of Science

An honors 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.

Program Requirements

Normally the requirements for the M.Sc. will consist of:

- Three full lecture courses (eighteen term contact hours)
- A thesis with a weight of two full courses which will be defended at an oral examination
- Participation in the seminar series of the institute
- The minimum number of lecture courses is one and a half (nine term contact hours) of which at least one (six term contact hours) must be at the graduate level

In special cases, the requirements may also be met by taking five full courses and no thesis. Then one of the courses must be the selected topics course 75.590T2. A comprehensive examination and participation in the seminar series will also be required.

Candidates admitted with more than the minimum lecture course requirements may be permitted to credit towards the degree a maximum of one full-course credit at the senior undergraduate level. (This maximum does not apply to qualifying-year students.)

Most incoming students will be expected to take 75.502T1.

Students in *theoretical* or *high energy physics* will normally include 75.561F1, 75.562W1, 75.571F1 and 75.572W1 among their courses.

For the *medical physics* program, the three areas of specialization are *imaging*, *therapy*, and *biophysics*. All students are required to take 75.523F1 and one appropriate physics half course from an area of physics other than medical physics. In addition:

- For imaging, 75.524W1 is required
- For therapy, 75.526W1 is required
- For biophysics, one half course chosen from 75.527F1, cell biology, physiology or anatomy is required

Students in *imaging* or *therapy* will be expected to obtain clinical experience as part of their program. A selection from 75.528W1 or, (with approval) other appropriate courses in physics, engineering, computer science, business or law can be used to complete the program.

Doctor of Philosophy

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 show outstanding academic performance and demonstrate signifi-cant promise for advanced research.

In exceptional cases, an outstanding student who has completed the honors 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 two full-course equivalents at the graduate level (twelve term contact hours)
- Students who lack any of the relevant courses recommended for the M.Sc. program will be expected to have completed them (or equiv-alents) by the end of their Ph.D. program. In addition, students in *high energy physics* or *theoretical physics* should complete 75.661 and 75.662.
- A comprehensive examination with emphasis on areas chosen by the candidate's advisory committee (an oral examination and/or a written examination normally at the end of the first full year of study)
- A thesis which will be defended at an oral examination. The examining board for all theses will include members of the institute from both Departments of Physics. The external examiner of the thesis will be external to both Departments of Physics
- Participation in the seminar series of the institute

Residence Requirements

For the M.Sc. degree:

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

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)

Graduate Courses*

Some of the following are regarded as the core courses and are taught either at Carleton University or at the University of Ottawa. The more specialized courses are only taught at the indicated campus. Most of the core courses will be offered each year, but only a selection of the others. If enrollment is small, a course may be given as a reading course. In addition to the formal prerequisites for a course, any course requires permission of the department.

The following courses may be offered either at Carleton University or the University of Ottawa.

- Physics 75.561F1 (PHY5966)
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.
Prerequisites: Physics 75.437 and 75.477.

- Physics 75.562W1 (PHY5967)
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: Physics 75.477.

- Physics 75.571F1 (PHY5170)
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.
Prerequisites: Physics 75.477 and 75.478.

- Physics 75.581F1 (PHY5140)
Methods of Theoretical Physics I
This course and Physics 75.582 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, and group theory.

The following courses are offered only at Carleton University.

- Physics 75.502T1 (PHY5344)
Computational Physics
The use and applicability of micro-, mini- and mainframe computers for solving physics prob-lems. Introduction to computer architectures, operating systems and networks commonly
encountered in physics experiments or applications. Programming techniques, use of libraries and graphics packages, with emphasis on packages in current use in major physics applications. Considerations of computer hardware, and interfacing computers to physics experiments. Statistical analysis, fitting and Monte Carlo methods with particular consideration to examples from particle physics and medical physics. Problems in numerical analysis, differ-ential equations, integration, etc. with emphasis on methods used for solving problems from
different areas of physics.
Prerequisite: Permission from the department.

- Physics 75.511F1 (PHY8111)
Classical Mechanics and Theory of Fields
Hamilton's principle; conservation laws; canonical transformations; Hamilton-Jacobi theory; Lagrangian formulation of classical field theory.

- Physics 75.522W1 (PHY8122)
Special Topics in Molecular Spectroscopy
Topics of current interest in molecular spectroscopy. In past years, the following areas have been covered: 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 offered as Chemistry 65.509/CHM8150)

- Physics 75.523F1
Medical Radiation Physics
Basic interaction of electromagnetic radiation with matter. Sources: x-ray, accelerators, nuclear. Charged particle interaction mecha-nisms, stopping powers, kerma, dose. Introduction to dosimetry. Units, measurements, dosi- metry devices.
Prerequisite: Permission of the instructor.

- Physics 75.524W1 (PHY5112)
Physics of Medical Imaging
Outline of the principles of transmission x-ray imaging, computerized tomography, nuclear medicine, magnetic resonance imaging, and ultrasound. Physical descriptors of image quality, including contrast, resolution, signal-to-noise ratio, and modulation transfer function are covered and an introduction is given to image processing.
Prerequisites: Physics 75.523 or equivalent, and one of Physics 75.424 or 75.427 or equivalent.

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*F,W,S indicates term of offering. Courses offered in the fall *and* winter will be followed by T.

The number following the letter indicates the credit weight of the course: 1 denotes a half-course credit, 2 denotes a full-course credit, etc.

- Physics 75.526W1

Medical Radiotherapy Physics
Terminology and related physics concepts. Bragg-Gray, Spencer-Attix cavity theories, Fano's theorem. Dosimetry protocols, dose distribution calculations. Radiotherapy devices, hyperthermia.
Prerequisite: Physics 75.523 or equivalent.

- Physics 75.527F1 (PHY5165)

Radiobiology
Introduction to basic physics and chemistry of radiation interactions, free radicals, oxidation and reduction, G values. Subcellular and cellular effects: killing, repair, sensitization, protection. Measurement methods. Survival curve models. Tissue effects, genetic and carcinogenic effects, mutations, hazards. Cancer therapy. Radiation protection considerations.
Prerequisite: Physics 75.523F1 or equivalent must have been taken, or be taken concurrently.

- Physics 75.528W1

Radiation Protection
Biophysics of radiation hazards, dosimetry and instrumentation. Monitoring of sources, planning of facilities, waste management, radiation safety, public protection. Regulatory agencies.
Prerequisite: Physics 75.523 or equivalent.

- Physics 75.532W1 (PHY8132)

Classical Electrodynamics
Covariant formulation of electrodynamics; Lenard-Wiechert potentials; radiation reaction; plasma physics; dispersion relations.
*Prerequisite:*Physics 75.437 or equivalent.

- Physics 75.564W1 (PHY8164)

Intermediate Nuclear Physics
Properties of the deuteron and the neutron-proton force. Nucleon-nucleon forces, isospin and charge independence. Nuclear models; single particle shell model, shell model with interactions, pairing, quasiparticles, collective models, deform-ed shell model. Scattering theory; effective range theory, partial wave analysis, phase shifts. Interpretation of n-p and p-p scattering experiments. Interaction of nucleons with electrons. Interaction of nuclei with radiation; multipole fields, transition rates, selection rules, internal conversion.
Prerequisite: Physics 75.468 or equivalent.

- Physics 75.572W1 (PHY8172)

Relativistic Quantum Mechanics
Relativistic wave equations. Expansion of S matrix in Feynman perturbation series. Feynman rules. An introduction to quantum electro-dynamics without second quantization. Gauge theories and the standard model.
Prerequisite: Physics 75.571.

- Physics 75.582W1 (PHY5141)

Methods of Theoretical Physics II
This course complements 75.581.Topics include group theory, discussion of SU_2, SU_3, and other symmetry groups. Lorentz group. Integral equations and eigenvalue problems.

- Physics 75.590T2 (PHY8290)

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 in Physics 75.590 will be counted for credit. Not more than one selected topic may be taken for credit in any one academic year.

- Physics 75.591F1, W1, S1 (PHY8191)

Selected Topics in Physics (M.Sc.)

- Physics 75.599F, W, S (PHY7999)

M.Sc. Thesis

- Physics 75.661 (PHY8161)

Particle Physics Phenomenology
This course covers much of the basic knowledge for both experimental and theoretical particle physics. Topics may include: accelerators, properties of detectors, low energy spectroscopy, standard model, tests of QCD and introduction to grand unified models.
Prerequisite: Physics 75.562 or equivalent.

- Physics 75.662 (PHY8162)

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: Permission of the department.

- Physics 75.671F1 (PHY8173)

Quantum Electrodynamics
Relativistic quantum field theory; second quantization of Bose and Fermi fields; reduction and LSZ formalism; perturbation expansion and proof of renormalizability of quantum electrodynamics; calculations of radiative corrections and applications.
Prerequisites: Physics 75.511, 75.532, 75.571 and 75.572.

- Physics 75.690T1 (PHY8490)

Selected Topics in Physics (Ph.D.)

- Physics 75.691F1, W1 (PHY8391)

Selected Topics in Physics (Ph.D.)

- Physics 75.699F, W, S (PHY9999)
Ph.D. Thesis

The following courses, offered at the University of Ottawa, may be taken for credit by Carleton students.

- Physics 74.503 (PHY5342)
Computer Simulations in Physics.
A course aimed at exploring physics with a computer in situations where analytic methods fail. Numerical solutions of Newton's equations, non-linear dynamics. Molecular dynamics simulations. Monte-Carlo simulations in statistical physics: the Ising model, percolation, crystal growth models. Symbolic computation in classical and quantum physics. Cannot be combined for credit with 75.502 (PHY5344).
Prerequisites: PHY3355 (PHY3755), PHY3370 (PHY3770), and familiarity with FORTRAN, Pascal or C.

- Physics 74.541F1 (PHY5100)
Solid State Physics I
Periodic structures, Lattice waves. Electron states. Static properties of solids. Electron-electron interaction. Dynamics of electrons. Transport properties. Optical properties.

- Physics 74.542 (PHY5110)
Solid State Physics II
Elements of group theory. Band structure, tight binding and other approximations, Hartree-Fock theory. Measuring the Fermi surface. Boltzmann equation and semiconductors. Diamagnetism, paramagnetism and magnetic ordering. Superconductivity.

- Physics 74.543 (PHY5151)
Type I and II Superconductors
Flux flow and flux cutting phenomena. Clem general critical state model. Flux quantization, Abrikosov vortex model and Ginzburg-Landau theory. Superconducting tunnelling junctions (Giaevar and Josephson types).
Prerequisite: PHY4370.

- Physics 74.547 (PHY5380)
Semiconductor Physics I
Brillouin zones and band theory. E-k diagram, effective mass tensors, etc. Electrical properties of semiconductors. Conduction, hall effect, magneto-resistance. Scattering processes. Multi-valley models and non-parabolic bands.
Prerequisite: PHY4380 or equivalent.

- Physics 74.548 (PHY5381, PHY5381)
Semiconductor Physics II — Optical Properties
Optical constants and dispersion theory. Optical absorption, reflection and band structure. Absorption at band edge and excitons. Lattice, defect and free carrier absorption, Magneto-optics. Photo-electronic properties, luminescence, detector theory. Experimental methods.
Prerequisite: PHY4380 or equivalent.

- Physics 74.549 (PHY5951)
Low Temperature Physics II
Helium 3 and Helium 4 cryostats. Dilution refrigerators. Theory and techniques of adia-batic demagnetization. Thermometry at low temperatures. Problems of thermal equilibrium and of thermal isolation. Properties of matter at very low temperature.
Prerequisite: PHY4355 or equivalent.

- Physics 74.551 (PHY5125)
Charged Particle Dynamics
A course on the acceleration, transport and focusing of charged particles in vacuum using electric magnetic fields. Beam optics. Phase space of an assembly of particles. Applications to experimental systems.

- Physics 74.553 (PHY5340)
Application of Advanced Computational Methods in Physics
Brief introduction to the number representation on a digital computer. Applications of methods of numerical optimization to calculate energy eigenvalues in quantum mechanics. Techniques of fitting experimental data. Numerical integrations and their application to distribution functions in statistical mechanics and special functions in theoretical physics. Numerical solutions of differential equations in physics.

- Physics 74.555 (PHY5355)
Statistical Mechanics
Ensemble Theory. Interacting classical and quantum systems. Phase transitions and critical phenomena. Fluctuations and linear response theory. Kinetic equations.
Prerequisites: PHY4370 and PHY3355.

- Physics 74.556 (PHY5742)
Simulations Numériques en Physique
Un cours ayant pour but d'étudier la physique à l'aide d'un ordinateur dans des situations où les méthodes analytiques sont inadéquates. Solutions numériques des équations de Newton. Dynamique non-linéaire. Simulations de dynamique moléculaire. Simulations Monte-Carlo en physique statistique: modèle d'Ising, percolation, croissance critalline. Calcul symbolique en phy-

sique classique et quantique. Ce cours exclut les crédits de 75.502(PHY5344)
Prélables: PHY3755 (PHY3355), PHY3770 (PHY3770) et connaissance d'un des langages FORTRAN, Pascal ou C.

- Physics 74.557 (PHY5922)

Advanced Magnetism I
Study of some of the experimental and theoretical aspects of magnetic phenomena found in ferro-, ferri-, antiferro-magnetic and spin glass materials. Topics of current interest in magnetism.
Prerequisite: PHY4385 or equivalent.

- Physics 74.563 (PHY5310)

Ion Collisions in Solids
Energy loss of energetic particles in passing through solids. Stopping cross sections. The influ-ence of crystal lattice on nuclear stopping. Crystal lattice effects at high energies. Channelling and blocking. The collision cascade. Charge states of fast ions in solids from thin foil and x-ray measurements.

- Physics 74.573 (PHY6170)

Advanced Quantum Mechanics II
Systems of identical particles and many-body theory. Lattice and impurity scattering. Quantum processes in a magnetic field. Radiative and non-radiative transitions. Introduction to relativistic quantum mechanics.
Prerequisite: PHY5170 or equivalent.

- Physics 74.642 (PHY6180)

Symmetry Properties of the Solid State II
Introduction to group theory. Group representations. Abelian groups, irreducible represent-ations, etc. Application to crystallographic point groups. Reciprocal lattice and Brillouin zones. Wave vector group. Spin-orbit coupling.
Prerequisite: PHY5180 or equivalent.

- Physics 74.644 (PHY6920)

Advanced Magnetism II
Selected topics in nuclear and electronic magne-tic resonances.
Prerequisite: PHY5920.

- Physics 74.645 (PHY7181)

Some Applications of Crystal Field Theory
Effect of crystalline electric field and magnetic interactions on magnetic centres in solids. Energy level splittings. Spin Hamiltonian formulation. Paramagnetic resonance. Magnetic susceptibility. Optical transitions, etc.
Prerequisite: PHY6180.

- Physics 74.646 (PHY6382)

Physics of Semiconductor Superlattices
Fundamental physics of two-dimensional quantized semiconductor structures. Electronic and optical properties of superlattices and quantum wells. Optical and electronic applications. This course is intended for students registered for the Ph.D. in semiconductor physics research.
Prerequisite: Advanced undergraduate or graduate course in solid state physics.

- Physics 74.647 (PHY6782)

Physique des super-réseaux à semiconducteurs
Physique fondamentale des structures quantiques bi-dimensionnelles à semiconducteurs. Propriétés électroniques et optiques des super-réseaux et puits quantiques. Applications à l'électronique et à l'optique. Ce cours est destiné aux étudiants et aux étudiantes inscrits au doctorat en physique des semiconducteurs.
Préalable: Cours sénior ou diplômé en physique de l'état solide.