PHYSICS (PHYS)

PHYS P22 Physics Frontiers: From Colliding Black Holes to Disruptive Technologies Units: 3.00
A descriptive course exploring concepts in physics at the frontiers of active research. Bypassing jargon and mathematical complexities, students will focus on the big questions at the extremes of our understanding of the universe around us. Designed for non-scientists who want to learn how we try to understand our fantastic, physic natural world.
Learning Hours: 114 (24 Lecture, 24 Practicum, 36 Online Activity, 18 Off-Campus Activity, 12 Private Study)
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Demonstrate basic science literacy i.e., strong physics critical thinking skills; an understanding of the relevant quantities (and units) and foundational physics relationships so that you can make simple predictions about issues that are relevant to you, your community and the world.
2. Create and implement simple experiments to demonstrates key physics principles relevant to frontier physics, and use the results to evaluate one or more possible models.
3. Evaluate the quality and accuracy of various physics resources.
4. Assess the effectiveness and supportiveness of their group members (and yourself).
5. Synthesize ideas from several sources to create and present an original physics teaching artifact/ demonstration.
6. Describe active frontiers of physics research and their potential impact on society.

PHYS 104 Fundamental Physics Units: 6.00
Mechanics, including systems of particles and rigid body motion; gravitation; fluids; electricity and magnetism; oscillatory motion and waves; topics in modern physics. The material is presented at a more fundamental level appropriate for students who are seeking a deeper appreciation of physics, and who may be considering a concentration in Physics.
Learning Hours: 240 (72 Lecture, 36 Laboratory, 36 Tutorial, 96 Private Study)
Requirements: Prerequisite None. Corequisite (MATH 120 or MATH 121 or [MATH 123 and MATH 124]). Exclusion PHYS 106; PHYS 115; PHYS 116; PHYS 117/6.0; PHYS 118; PHYS 119. Recommended 4U Physics.
Offering Faculty: Faculty of Arts and Science

PHYS 106 General Physics Units: 6.00
Mechanics, including systems of particles and rigid body motion; fluids; electricity and magnetism; oscillatory motion and waves; heat, light and sound; topics in modern physics. Aspects of physics useful for further work in other sciences will be emphasized.
NOTE Also offered at the Bader College, UK. Learning Hours may vary.
Learning Hours: 240 (72 Lecture, 36 Laboratory, 36 Tutorial, 96 Private Study)
Requirements: Prerequisite None. Corequisite (MATH 120 or MATH 121 or [MATH 123 and MATH 124]). Exclusion PHYS 104; PHYS 115; PHYS 116; PHYS 117/6.0; PHYS 118; PHYS 119. Recommended 4U Physics.
Offering Faculty: Faculty of Arts and Science

PHYS 115 Introduction to Physics I Units: 3.00
An algebra-based course dealing with basic physics concepts, including dynamics, fluids, and basic thermodynamics.
PHYS 115 includes a required lab component.
NOTE PHYS 115 and PHYS 116 together, are equivalent to PHYS 117/6.0.
NOTE Manual: estimated cost $10.
Learning Hours: 132 (36 Lecture, 12 Laboratory, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite None. Exclusion PHYS 104; PHYS 106; PHYS 117/6.0; PHYS 118; PHYS 119.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Analyze the information contained in various hypothetical problem scenarios within the context of recognizable physics laws and apply systematic problem-solving strategies to solve for unknown quantities.
2. Identify and interpret the laws of nature as summarized by the fundamental concepts that constitute the foundation of classical physics.
3. Interpret and apply basic experiment methodologies designed to test fundamental concepts through direct observation.
4. Quantitatively analyze measurement results with effective evaluation of experimental uncertainties.
5. Relate nature's basic laws describing forces, motion, energy, momentum, thermodynamics, and the conservation rules that constrain these laws to real world applications.

PHYS 116 Introduction to Physics II Units: 3.00
An algebra-based course dealing with basic physics concepts, including waves, electromagnetism, and basic optics.
PHYS 116 includes a required lab component.
NOTE PHYS 115 and PHYS 116 together, are equivalent to PHYS 117/6.0.
NOTE Manual: estimated cost $10.
Learning Hours: 132 (36 Lecture, 12 Laboratory, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 115. Exclusion PHYS 104; PHYS 106; PHYS 117/6.0; PHYS 118; PHYS 119.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Analyze the information contained in various hypothetical problem scenarios within the context of recognizable physics laws and apply systematic problem-solving strategies to solve for unknown quantities.
2. Identify and interpret the laws of nature as summarized by the fundamental concepts that constitute the foundation of classical physics.
3. Interpret and apply basic experiment methodologies designed to test fundamental concepts through direct observation.
4. Quantitatively analyze measurement results with effective evaluation of experimental uncertainties.
5. Relate nature's basic laws describing forces, motion, energy, waves, electromagnetism, optics, and the conservation rules that constrain these laws to real world applications.

PHYS 118 Basic Physics Units: 6.00
An algebra-based course dealing with basic Physics concepts, including dynamics, fluids, waves, electromagnetism, and basic optics. Emphasis is placed on the development of problem-solving skills through the use of Mastery based course delivery.
NOTE Only offered online. Consult Arts and Science Online.
Learning Hours: 228 (132 Online Activity, 96 Private Study)
Requirements: Prerequisite None. Recommended 4U Physics. Exclusion PHYS 104/6.0; PHYS 106/6.0; PHYS 115/3.0; PHYS 116/3.0; PHYS 117/6.0.
Course Equivalencies: PHYS 118/118B
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Students will apply nature's basic laws describing forces and motion, energy and momentum, and the conservation rules that constrain these laws to real world applications.
2. Students will be able to analyze the information contained in various problem scenarios within the context of recognizable physics laws and utilize systematic problem-solving strategies to solve for unknown quantities.
3. Students will be able to identify and interpret the laws of nature as summarized by the fundamental concepts that constitute the foundations of classical physics.

PHYS 119 Introductory Physics Laboratory Units: 1.50
This is the laboratory portion of PHYS 117, offered for students who completed the online PHYS 118 Basic Physics course, but would like a laboratory experience. A laboratory class in mechanics, electricity, waves and optics. This course runs 8 experiments through the fall and winter terms.
Requirements: Prerequisite PHYS 118/6.0. Exclusion PHYS 104/6.0; PHYS 106/6.0; PHYS 115/3.0; PHYS 116/3.0; PHYS 117/6.0.
Offering Faculty: Faculty of Arts and Science

PHYS 206 Dynamics Units: 3.00
An introductory course in classical dynamics of particles, of rigid bodies and of fluids that sets the foundation for more advanced work. Topics include kinematics of particles and of rigid bodies, central forces, kinetics of systems of particles, planar and three dimensional dynamics of rigid bodies and an introduction to fluid mechanics.
Requirements: Prerequisite ([PHYS 104 or PHYS 106] and [MATH 120 or MATH 121]) or permission of the Department. Recommended A minimum grade of a C in PHYS 104 or PHYS 106.
Offering Faculty: Faculty of Arts and Science

PHYS 212 Oscillations, Waves, and Optics Units: 3.00
Fundamentals of free, damped and forced vibrations with applications to various mechanical systems. Coupled oscillations and normal modes. Classical wave equation, standing and travelling waves. Introduction to optics: lenses and mirrors, image formation and optical instruments, optical resolution.
Learning Hours: 120 (24 Lecture, 24 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 206/3.0 and PHYS 242/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Describe and model the following: Fundamentals of free, damped, and forced vibrations with applications to various mechanical systems. Coupled oscillations and normal modes. Classical wave equation, standing and travelling waves. Lenses and mirrors, image formation and optical instruments, optical resolution.
2. Derive the classical wave equation and be fully conversant with classical wave behavior, such as refraction, diffraction, interference, and the superposition of waves.
3. Identify normal modes in coupled oscillators.
4. Relate the concepts listed above to real work applications.
5. Solve these differential equations to obtain the response of the mechanical (or electrical) system analytically or numerically using modern software packages such as MATLAB, Python, or Mathematica.
6. Model image formation in multi-element optical systems.

PHYS 213 Computational Methods in Physics Units: 3.00
Computing environments, algorithms, techniques and programming for solving physics problems. Numerical methods. Code development. Possible topics to be covered include numerical differentiation and integration, root finding and optimization problems, solution of linear systems of equations, Monte Carlo simulation, and symbolic computation.
Learning Hours: 120 (24 Lecture, 24 Tutorial, 72 Private Study)
Requirements: Prerequisite (PHYS 104 or PHYS 106) and (MATH 120 or MATH 121). Exclusion MATH 272; PHYS 313.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Analyze a physical problem, reducing the problem to study the key factors influencing the evolution of the system, and derive a system of equations to model the behaviour of the resulting system.
2. Create, run and analyze the output (graphically and otherwise) of computer programs, in a Python computing environment.
3. Design the appropriate computer algorithm to solve the resulting equations and to implement it in well-documented, clearly written code (Python).
4. Synthesize the entire process above and create a clear, concise written report summarizing the key results.
5. Test the resulting code using known results in simple examples and interpret the results of simulations in more general cases, determining the influence of each parameter affecting the outcome.

PHYS 216 Introduction to Astrophysics Units: 3.00
Broad overview of basic laws of gravitation, radiation, and relativity: history and evolution of modern astronomy; ground and space-based astronomy; the physics and evolution of stars; the milky way; galaxies in the universe; and cosmology. This course also uses the on-campus observatory at an introductory level.
Requirements: Prerequisite ([PHYS 104 or PHYS 106] and [MATH 120 or MATH 121]) or permission of the Department.
Offering Faculty: Faculty of Arts and Science

PHYS 239 Electromagnetism Units: 3.00
The experimental basis and mathematical description of electrostatics, magnetostatics and electromagnetic induction, together with a discussion of the properties of dielectrics and ferromagnetics, are presented. Both the integral and vector forms of Maxwell's equations are deduced.
Requirements: Prerequisite (PHYS 104 or PHYS 106) and (MATH 221 or MATH 227 or MATH 280). Recommended A minimum grade of a C in PHYS 104 or PHYS 106.
Offering Faculty: Faculty of Arts and Science

PHYS 242 Relativity and Quanta Units: 3.00
Evidence for relativistic effects. Kinematics and dynamics in special relativity, space-time diagrams, applications. Waves and the wave nature of light and matter. Evidence for quanta, spectra, Bohr atom. Introduction to the Schrödinger equation.
Requirements: Prerequisite PHYS 104/6.0 or PHYS 106/6.0. Recommended Minimum grade of C in PHYS 104/6.0 or PHYS 106/6.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Understand the wave equation and the propagation of harmonic waves, including electromagnetic radiation.
2. Understand and apply basic transformations between different reference frames in Special Relativity.
3. Draw and read spacetime diagrams.
4. Model collisions between relativistic particles.
5. Describe the key phenomena of thermal radiation and determine its properties.
6. Understand the wave and particle nature of matter and light and its implications.
7. Understand the Schrödinger equation and the connection between the quantum mechanical description of nature and non-intuitive phenomena such as Heisenberg's Uncertainty Principle and quantum tunneling.

PHYS 250 Foundations of Experimental Physics Units: 3.00
Laboratory and lecture course that presents techniques and skills that are the foundations of experimental physics. Topics include statistical analysis of data, uncertainties in measurement, propagation of errors, software for data analysis, graphing and reporting. Students will be exposed to techniques in the measurement of electric, magnetic, thermal and mechanical properties. Laboratories also illustrate some principles of quantum physics, mechanics, electromagnetism and thermodynamics learned in other physics courses. Some exposure to computerized data acquisition is included.
Learning Hours: 132 (24 Lecture, 36 Laboratory, 72 Private Study)
Requirements: Prerequisite PHYS 104 or PHYS 106.
Offering Faculty: Faculty of Arts and Science

PHYS 315 Physical Processes in Astrophysics Units: 3.00
This course relates observable quantities to the physical properties of astronomical sources thereby deciphering the varied nature of the cosmos. Basic physical processes in astrophysics are discussed and applied to diverse systems including planets, stars, the interstellar medium and distant galaxies. Topics include radiative transfer and the perturbation of the signal by instruments, the atmosphere, and the interstellar medium. The main astrophysical emission processes, both continuum and line, are also presented. An observing project will be carried out during the term.
Learning Hours: 120 (36 Lecture, 84 Private Study)
Requirements: Prerequisite (PHYS 216 and PHYS 242) or permission of the Department.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Calculate the various extraneous effects that degrade astronomical information (the light from celestial sources) as the signal passes through the interstellar medium, the Earth's atmosphere, and the detector.
2. Design and carry out a straightforward observing project, and analyze data from a real astronomical telescope to develop an understanding of some of the practical limitations in such scientific investigations.
3. Distinguish between the various wavelength, energy and frequency domains at which astronomers make their observations, and be able to explain the importance of working in these different spectral domains for a full understanding of the physics of the sources.
4. Explain the fundamental interactions between light and atoms/molecules/dust particles that determine the radiative output of astronomical sources.
5. Invert received astronomical signals to derive astrophysical conclusion about the physical nature of the source.

PHYS 316 Methods in Mathematical Physics I Units: 3.00
Methods of mathematics important for physicists. Complex arithmetic, series expansions and approximations of functions, Fourier series and transforms, vector spaces and eigenvalue problems, ordinary differential equations and Green's functions.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite (MATH 221 or MATH 227 or MATH 280) and (MATH 225 or MATH 231 or MATH 232). Exclusion MATH 334; MATH 338; PHYS 312.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Algebraically manipulate complex numbers and complex exponentials.
2. Apply the standard methods of mathematical physics, such as Green's functions, to solve ordinary differential equations.
3. Apply the techniques of linear vector spaces to problems in classical and quantum mechanics.
4. Compute Fourier series and transforms of elementary functions.

PHYS 317 Methods in Mathematical Physics II Units: 3.00
A continuation of PHYS 316. Partial differential equations, functions of a complex variable and contour integration, and special topics such as probability and statistics, group theory and non-linear dynamics.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 316. Exclusion MATH 228; MATH 326; MATH 338; PHYS 312.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Apply the methods of complex analysis and Green's functions to the wave equation and other common equations of physics.
2. Apply the techniques of complex analysis to the computation of integrals via the residue theorem and contour integration.
3. Apply the techniques of mathematical physics such as separation of variables to solve partial different equations commonly encountered in physics.
4. Develop a working knowledge of functions of a complex variable, including the calculation of Laurent expansions.
5. Develop a working knowledge of the special functions of mathematical physics, such as Bessel functions and Legendre polynomials.
6. Develop an understanding of one or more special topics in mathematical physics such as probability and statistics, group theory, or nonlinear dynamics.

PHYS 321 Advanced Mechanics Units: 3.00
An introduction to the equations of mechanics using the Lagrange formalism and to the calculus of variations leading to Hamilton's principle. The concepts developed in this course are applied to problems ranging from purely theoretical constructs to practical applications. Links to quantum mechanics and extensions to continuous systems are developed.
Requirements: Prerequisite PHYS 212 and (MATH 221 or MATH 227 or MATH 280) and (MATH 225 or MATH 231 or MATH 232).
Offering Faculty: Faculty of Arts and Science

PHYS 332 Electromagnetic Theory Units: 3.00
Electromagnetic theory and applications. Topics include: Maxwell's equations, gauge theory, relativistic transformations of Maxwell's equations, properties of waves in free space, dielectrics, conductors and ionized media, reflection and refraction at the surfaces of various media, propagation in metallic and dielectric waveguides, radiation of electromagnetic waves from charged particles and antennae.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 239/3.0 and (MATH 221/3.0 or MATH 280/3.0) and (MATH 225/3.0 or MATH 231/3.0). Exclusion PHYS 432/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Apply each of Maxwell's equations and the Lorentz force law to solve problems involving charge and current distributions and electromagnetic fields.
2. Manipulate equations using methods from vector calculus and apply the integral and differential forms of Maxwell's equations as appropriate.
3. Apply conservation of energy and momentum principles to solve problems involving fields and charges.
4. Solve problems involving the propagation of electromagnetic waves in free space and in waveguides.
5. Relate the theories of special relativity and electromagnetism and solve problems involving charges and extended objects moving at relativistic speeds.

PHYS 334 Electronics for Physicists Units: 3.00
The design of electronic circuits and systems, using commonly available devices and integrated circuits. The properties of linear circuits are discussed with particular reference to the applications of feedback; operational amplifiers are introduced as fundamental building blocks. Digital circuits are examined and the properties of the commonly available I.C. types are studied; their use in measurement, control and signal analysis is outlined. Laboratory work is closely linked with lectures and provides practical experience in the subjects covered in lectures.
Requirements: Prerequisite PHYS 239.
Course Equivalencies: PHYS333, PHYS334
Offering Faculty: Faculty of Arts and Science

PHYS 344 Introduction to Quantum Mechanics Units: 3.00
Matter waves. Postulates of wave mechanics. Stationary states and one-dimensional potentials. Particle tunneling and scattering states. Introduction to matrix mechanics and Dirac notation. Quantized angular momentum, and the H atom.
NOTE Manual: estimated cost $20.
Requirements: Prerequisite PHYS 212 and PHYS 242 and (MATH 221 or MATH 280) and (MATH 225 or MATH 231 or MATH 232). Equivalency PHYS 343.
Course Equivalencies: PHYS343, PHYS344
Offering Faculty: Faculty of Arts and Science

PHYS 345 Quantum Physics of Atoms, Nuclei, and Particles Units: 3.00
Spin. Addition of angular momentum. Many electron atoms and the periodic table. Introduction to perturbation theory and Fermi's golden rule. Time dependent perturbations, including stimulated emission. Introduction to nuclear and particle physics.
NOTE Manual: estimated cost $20.
Requirements: Prerequisite PHYS 344/3.0. Equivalency PHYS 424/3.0*.
Course Equivalencies: PHYS345, PHYS424
Offering Faculty: Faculty of Arts and Science

PHYS 350 General Laboratory Units: 6.00
Experiments in heat, optics, electron physics, quantum physics, and radioactivity are performed. A substantial part of the course is an experimental project during the Winter Term. A topic for the experimental physics, or observational astronomy project will be assigned after discussion with the student.
Learning Hours: 234 (72 Laboratory, 12 Tutorial, 6 Online Activity, 144 Private Study)
Requirements: Prerequisite PHYS 239/3.0 and PHYS 242/3.0 and PHYS 250/3.0.
Offering Faculty: Faculty of Arts and Science

PHYS 372 Thermodynamics Units: 3.00
Temperature, equations of state, internal energy, first and second laws, entropy and response functions. Application to heat engines and refrigerators. Free energies, Legendre transformations, changes of phase. Introduction to the Boltzmann factor and statistical mechanics.
Requirements: PHYS242
Offering Faculty: Faculty of Arts and Science

PHYS 414 Introduction to General Relativity Units: 3.00
Einstein's theory of gravity is developed from fundamental principles to a level which enables the student to read some of the current literature. Includes an introduction to computer algebra, an essential element of a modern introduction to Einstein's theory.
Requirements: Prerequisite PHYS 316/3.0 and PHYS 321/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Appreciate Einstein's geometrization of gravity.
2. Compare and analyze various extensions to the theory of General Relativity.
3. Describe the various constituents of modern cosmology.
4. Extend spherically symmetric vacuum to the axially symmetric case.
5. Identify what is meant by a solution to Einstein's equations.

PHYS 417 Methods in Mathematical Physics II Units: 3.00
A continuation of PHYS 316. Partial differential equations, functions of a complex variable and contour integration, and special topics such as probability and statistics, group theory and non-linear dynamics.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 316/3.0. Exclusion MATH 228/3.0; MATH 326/3.0; MATH 338/3.0*; PHYS 317/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Apply the methods of complex analysis and Green's functions to the wave equation and other common equations of physics.
2. Apply the techniques of complex analysis to the computation of integrals via the residue theorem and contour integration.
3. Apply the techniques of mathematical physics such as separation of variables to solve partial different equations commonly encountered in physics.
4. Develop a working knowledge of functions in a complex variable, including the calculation of Laurent expansions.
5. Develop a working knowledge of the special functions of mathematical physics, such as Bessel functions and Legendre polynomials.
6. Develop an understanding of one or more special topics in mathematical physics such as probability and statistics, group theory or nonlinear dynamics.

PHYS 418 Physical Processes in Astrophysics Units: 3.00
This course relates observable quantities to the physical properties of astronomical sources thereby deciphering the varied nature of the cosmos. Basic physical processes in astrophysics are discussed and applied to diverse systems including planets, stars, the interstellar medium and distant galaxies. Topics include radiative transfer and the perturbation of the signal by instruments, the atmosphere, and the interstellar medium. The main astrophysical emission processes, both continuum and line, are also presented. An observing project will be carried out during the term.
Learning Hours: 120 (36 Lecture, 84 Private Study)
Requirements: Prerequisite (PHYS 216/3.0 and PHYS 242/3.0) or permission of the Department. Exclusion PHYS 315/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Calculate the various extraneous effects that degrade astronomical information (the light from celestial sources) as the signal passes through the interstellar medium, the Earth's atmosphere, and the detector.
2. Design and carry out a straightforward observing project, and analyze data from a real astronomical telescope to develop an understanding of some of the practical limitations in such scientific investigations.
3. Distinguish between the various wavelength, energy and frequency domains at which astronomers make their observations, and be able to explain the importance of working in these different spectral domains for a full understanding of the physics of the sources.
4. Explain the fundamental interactions between light and atoms/molecules/dust particles that determine the radiative output of astronomical sources.
5. Invert received astronomical signals to derive astrophysical conclusion about the physical nature of the source.

PHYS 432 Electromagnetic Theory Units: 3.00
Electromagnetic theory and applications. Topics include: Maxwell's equations, gauge theory, relativistic transformations of Maxwell's equations, properties of waves in free space, dielectrics, conductors and ionized media, reflection and refraction at the surfaces of various media, propagation in metallic and dielectric waveguides, radiation of electromagnetic waves from charged particles and antennae.
Requirements: Prerequisite PHYS 239 and (MATH 221 or MATH 280) and (MATH 225 or MATH 231 or MATH 232). Equivalency PHYS 332.
Course Equivalencies: PHYS332, PHYS432
Offering Faculty: Faculty of Arts and Science

PHYS 435 Stellar Structure and Evolution Units: 3.00
This course provides a detailed account of the formation, structure, evolution and endpoints of stars. Topics include the HR diagram, nuclear energy generation, radiative transport and stellar model building, supernovae, white dwarfs, neutron stars, pulsars and black holes.
Requirements: Prerequisite PHYS 216/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Describe and model the energy generation and transfer mechanisms reactions in stars.
2. Describe and model the evolutionary pathways of stars.
3. Describe and model the various endpoint of stellar evolution for stars of different masses.
4. Describe star formation mechanisms.
5. Explain limitations in observational data and comparisons to theoretical star formation models.

PHYS 444 Advanced Quantum Physics Units: 3.00
This course covers perturbation theory, scattering theory and the addition of angular momentum. Special topics may include: many-electron systems, path integral formulation of quantum mechanics, entanglement and quantum computing, quantum optics.
Requirements: Prerequisite PHYS 345. Equivalency PHYS 426.
Course Equivalencies: PHYS426, PHYS444
Offering Faculty: Faculty of Arts and Science

PHYS 445 Quantum Physics of Atoms, Nuclei, and Particles Units: 3.00
Spin. Addition of angular momentum. Many electron atoms and the periodic table. Introduction to perturbation theory and Fermi's golden rule. Time dependent perturbations, including stimulated emission. Introduction to nuclear and particle physics.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 344/3.0. Exclusion PHYS 345/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Apply the postulates of quantum mechanics to determine the outcomes of measurements on a variety of quantum systems.
2. Determine the quantum states of total angular momentum for different systems.
3. Use particle-exchange symmetry to characterize the energy levels of multi-particle systems.
4. Determine the quantum states of multielectron atoms and molecules.
5. Estimate the ground state energy of quantum systems using the variational method.
6. Determine the effects of perturbations on the energy levels of quantum systems.

PHYS 453 Advanced Physics Laboratory Units: 3.00
Advanced physics laboratory course providing students with experience in a range of experimental techniques and analysis. A selection of experiments are performed from fields including nuclear physics, applied physics, fluid mechanics, solid state physics, low-temperature physics and optics.
Learning Hours: 132 (76 Laboratory, 60 Private Study)
Requirements: Prerequisite PHYS 350/3.0 and (PHYS 344/3.0 or CHEM 313/3.0).
Offering Faculty: Faculty of Arts and Science

PHYS 454 Advanced Physics Design Project Units: 3.00
Groups of students in physics and engineering physics undertake a large design project of their choice that reflects and further develops their knowledge of physics. The students then build a prototype of their design to demonstrate the feasibility of the project within the design constraints.
Requirements: Prerequisite PHYS 350.
Offering Faculty: Faculty of Arts and Science

PHYS 460 Laser Optics Units: 3.00
Topics and applications in modern physical optics, culminating with the development of the laser and its current applications. Topics include: Gaussian beam propagation, optical resonators, Fourier optics, fiber optics, holography, light-matter interaction using classical and semi-classical models, and the basic theory and types of lasers.
Requirements: Prerequisite PHYS 239/3.0 and (PHYS 344/3.0 or CHEM 313/3.0). Corequisite PHYS 332/3.0 or PHYS 432/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Apply Maxwell's formalism to determine the characteristics of spatially coherent light propagating through free space and simple optical elements.
2. Apply the Lorentz model, to characterize classical light-matter interaction, including dispersion and absorption.
3. Apply the postulates of quantum mechanics to model semiclassical light-matter interaction (Maxwell-Bloch theory) and quantify optical amplification for particular systems.
4. Characterize the performance of various gain media and laser cavities to generate laser light.
5. Identify an interesting technical problem and explain how optics solves it or may solve it.

PHYS 472 Statistical Mechanics Units: 3.00
Phase space, the ergodic hypothesis and ensemble theory. Canonical and grand canonical ensembles. Partition functions. Ideal quantum gases. Classical gases and the liquid-vapour transition. Introduction to techniques for interacting systems, including Monte Carlo simulations.
Requirements: Prerequisite (PHYS 213 or PHYS 313) and PHYS 344 and PHYS 372. Exclusion CHEM 412.
Offering Faculty: Faculty of Arts and Science

PHYS 479 High Performance Computational Physics Units: 3.00
This course teaches students how to use the tools of high performance computing facilities, including communications protocol for parallel computations. Students will employ these facilities and tools and use various numerical algorithms in the solution of physics problems.
Learning Hours: 120 (24 Lecture, 24 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 213/3.0 and PHYS 344/3.0. Corequisite PHYS 332/3.0 or PHYS 432/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Communicate effective solution methods and results, both in terms of code and report writing.
2. Implement a variety of advanced numerical algorithms to solve problems in physics that require high performance computers.
3. Learn advanced numerical algorithms for simulation and modelling, and apply such approaches to different problems, including (i) the dynamics of interacting quantum systems, and (ii) boundary value problems in advanced electromagnetic theory.
4. Learn one example of a communications protocol for parallel computations, MPI (message passing interface), and will learn to write python codes that implement MPI.
5. Learn to compile and submit parallelized codes to distributed memory architecture machines (from Compute Canada).
6. Work on a variety of high performance computing sites, all linked by Compute Canada. Students will compile and submit parallelized codes to distributed memory architecture machines.
7. Work with one example of a communications protocol for parallel computations, MPI (message passing interface), and will develop python codes that integrate MPI.

PHYS 480 Solid State Physics Units: 3.00
A fundamental treatment of the properties of solids. Topics include: crystal structure, X-ray and neutron scattering, the reciprocal lattice, phonons, electronic energy bands, and the thermal, magnetic, optical and transport properties of solids.
Requirements: Prerequisite PHYS 344/3.0. Corequisite PHYS 445/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Apply the postulates of quantum mechanics to determine the outcomes of measurements on a variety of quantum systems.
2. Determine the quantum states of total angular momentum for different systems.
3. Use particle-exchange symmetry to characterize the energy levels of multi-particle systems.
4. Determine the quantum states of multielectron atoms and molecules.
5. Estimate the ground state energy of quantum systems using the variational method.
6. Determine the effects of perturbations on the energy levels of quantum systems.

PHYS 483 Nanoscience and Nanotechnology Units: 3.00
An examination of the key ideas, techniques and technologies in the fields of nanoscience and nanotechnology. Emphasis will be placed on the physics involved, measurement techniques, and technological applications. Topics covered are selected from the following: electrical and optical properties of quantum dots, quantum wires and nanotubes; quantum information technology; mesoscopic electronics; nanostructures on surfaces; and scanning-probe and optical microscopy.
Requirements: Prerequisite (PHYS 345/3.0 or PHYS 445/3.0 or CHEM 313/3.0) or permission of the Department.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Have a fundamental understanding of the underlying physics and engineering as it connects to nanoscience and nanotechnologies.
2. Understand the limits and advantages of fabrication, analysis and characterization tools for nanoscale materials and devices.
3. Read and analyze papers from the current research literature in a variety of fields.
4. Use effective oral communication and present a summary of research scientific research.
5. Be able to explain scientific results and ideas including critical analysis.

PHYS 490 Nuclear and Particle Physics Units: 3.00
A systematic introduction to nuclear and particle physics for advanced physics students. Topics include basic nuclear properties: size, mass, decay and reactions; shell model of nuclear structure; magnetic moments; gamma and beta decay; quark model of elementary particles; and strong, electromagnetic and weak interactions.
Requirements: Prerequisite PHYS 344/3.0.
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Describe low energy nuclear physics, including nuclear structure and basic interactions.
2. Describe particle physics including the quark model, the structure of mesons and hadrons, the fundamental forces and interactions.
3. Describe nuclear instability and model rates and properties for alpha, beta, and gamma decays, fusion and fission.
4. Describe the process for calculating particle interaction rates from first principles and the role of Feynman Diagrams.
5. Describe basic renormalization and model simple QED decay and annihilation processes from first principles.
6. Model nuclear and particle processes using 4-vectors and Special Relativity.
7. Describe the role of experiments in testing particle physics theories such as the Standard Model and describe limitations and extensions to particle physics theories.
8. Describe the role of nuclear and particle physics in the modern age including nuclear power (fission and fusion), nuclear medicine, and fundamental science.

PHYS 491 Physics of Nuclear Reactors Units: 3.00
The objective of this course is the understanding of the fundamental physics associated with a nuclear reactor. Topics include a brief review of basic nuclear physics, neutron interactions and cross-sections, neutron diffusion, neutron moderation, theory of reactors, changes in reactivity, control of reactors. Offered in alternate years.
NOTE Manual: estimated cost $15 to $25 per manual.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite Level 3 or above and registration in a (PHYS, ASPH or MAPH Plan).
Offering Faculty: Faculty of Arts and Science

PHYS 493 Plasma Physics Units: 3.00
An introduction to plasma physics. The motions of single particles under the influence of various fields is considered first, followed by a fluid description of plasma. Topics also include plasma properties, waves in plasma, equilibrium and stability.
Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)
Requirements: Prerequisite PHYS 239/3.0 and (MATH 225/3.0 or MATH 231/3.0) and (MATH 221/3.0 or MATH 280/3.0).
Offering Faculty: Faculty of Arts and Science
Course Learning Outcomes:

1. Have a working definition of what constitutes a plasma.
2. Describe the motion of charged particles under the influence of various applied fields.
3. Be familiar with adiabatic invariants.
4. Develop a basic understanding of plasma as a fluid including the governing magnetohydrodynamic.
5. Be familiar with the propagation of waves in plasma.
6. Describe diffusion processes, collision processes, and plasma resistivity.
7. Be aware of various plasma instabilities.

PHYS 495 Introduction to Medical Physics Units: 3.00
Topics include: the production and measurement of X-rays and charged particles for radiation therapy and nuclear medicine; interactions of radiation with matter and biological materials; interaction coefficients and radiation dosimetry; radiation safety; physics of medical imaging with examples from nuclear medicine, ultrasound and magnetic resonance imaging.
Requirements: Prerequisite Level 3 or above and registration in a (PHYS, ASPH or MAPH Plan).
Offering Faculty: Faculty of Arts and Science

PHYS 590 Research Thesis Units: 6.00
Investigation of a contemporary research topic in physics or astronomy under the supervision of a faculty member, and leading to a written thesis and an oral presentation of results.
Requirements: Prerequisite Level 4 or above and registration in a (PHYS, ASPH or MAPH Plan).
Offering Faculty: Faculty of Arts and Science

PHYS 594 Independent Study Units: 3.00
Exceptionally qualified students entering their third- or fourth-year may take a program of independent study provided it has been approved by the Department or Departments principally involved. The Department may approve an independent study program without permitting it to be counted toward a concentration in that Department. It is, consequently, the responsibility of students taking such programs to ensure that the concentration requirements for their degree will be met.
NOTE Requests for such a program must be received one month before the start of the first term in which the student intends to undertake the program.
Requirements: Prerequisite Permission of the Department or Departments principally involved.
Offering Faculty: Faculty of Arts and Science