

# PHYSICS-PH (PH)

## Courses

### PH 110 Physics of Everyday Phenomena (GT-SC2) Credits: 3 (3-0-0)

**Course Description:** Fundamental concepts of physics and elementary quantitative reasoning applied to phenomena in everyday life and beyond.

**Prerequisite:** None.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**Additional Information:** Biological & Physical Sciences 3A, Natural & Physical Sciences w/o lab (GT-SC2).

### PH 111 Physics of Everyday Phenomena Laboratory (GT-SC1) Credit: 1 (0-2-0)

**Course Description:** Experiments dealing with basic physics concepts including explorations of everyday phenomena.

**Prerequisite:** PH 110, may be taken concurrently.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**Additional Information:** Biological & Physical Sciences 3A, Natural & Physical Sciences w/ lab (GT-SC1).

### PH 121 General Physics I (GT-SC1) Credits: 5 (3-2-1)

**Course Description:** Concepts of force, torque, energy, momentum, work used to cover fluids, waves, sound, temperature, heat; biological, physical examples (noncalculus).

**Prerequisite:** MATH 120 and MATH 125, may be taken concurrently or MATH 124 and MATH 125, may be taken concurrently or MATH 127 or MATH 141 and MATH 125, may be taken concurrently or MATH 155, may be taken concurrently or MATH 156, may be taken concurrently or MATH 157, may be taken concurrently or MATH 160, may be taken concurrently.

**Registration Information:** Must register for lecture, lab, and recitation. Credit not allowed for both PH 121 and PH 141.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**Additional Information:** Biological & Physical Sciences 3A, Natural & Physical Sciences w/ lab (GT-SC1).

### PH 122 General Physics II (GT-SC1) Credits: 5 (3-2-1)

**Course Description:** Electricity including electrostatics and simple circuits; magnetism; optics; nuclear physics, radiation; biological, physical examples (noncalculus).

**Prerequisite:** PH 121 or PH 141.

**Registration Information:** Must register for lecture, lab, and recitation. Credit not allowed for both PH 122 and PH 142.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**Additional Information:** Biological & Physical Sciences 3A, Natural & Physical Sciences w/ lab (GT-SC1).

### PH 141 Physics for Scientists and Engineers I (GT-SC1) Credits: 5 (3-2-1)

**Course Description:** Forces, energy, momentum, angular momentum, oscillations, waves, heat, thermodynamics (calculus based).

**Prerequisite:** None.

**Registration Information:** (MATH 126 or concurrent registration; MATH 155 or concurrent registration) or (MATH 127 or concurrent registration; MATH 155 or concurrent registration) or MATH 159 or concurrent registration or MATH 160 or concurrent registration. Must register for lecture, lab, and recitation. Credit not allowed for both PH 121 and PH 141.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**Additional Information:** Biological & Physical Sciences 3A, Natural & Physical Sciences w/ lab (GT-SC1).

### PH 142 Physics for Scientists and Engineers II (GT-SC1) Credits: 5 (3-2-1)

**Course Description:** Electricity and magnetism, circuits, light, optics (calculus based).

**Prerequisite:** (PH 141) and (MATH 161, may be taken concurrently or MATH 255, may be taken concurrently or MATH 271, may be taken concurrently).

**Registration Information:** Must register for lecture, lab, and recitation. Credit not allowed for both PH 142 and PH 122.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**Additional Information:** Biological & Physical Sciences 3A, Natural & Physical Sciences w/ lab (GT-SC1).

### PH 193 Introductory Seminar in Physics Credit: 1 (0-0-1)

**Course Description:** An orientation to the discipline of physics and the undergraduate major.

**Prerequisite:** None.

**Restrictions:** Must not be a: Junior, Senior. Must be a: Undergraduate.

**Registration Information:** Credit not allowed for both PH 180A2 and PH 193.

**Term Offered:** Fall.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

### PH 210 Introduction to Computing in Physics Credits: 3 (3-0-0)

**Course Description:** An introduction to the use of computers in physics focusing on the design, implementation, and application of algorithms used to solve common physics problems, utilizing Python.

**Prerequisite:** (CS 150B or CS 152) and (PH 141).

**Term Offered:** Fall.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

### PH 245 Introduction to Electronics Credits: 3 (2-3-0)

**Course Description:** AC circuits, physical bases and applications of electronic devices.

**Prerequisite:** MATH 161 and PH 142.

**Registration Information:** Must register for lecture and laboratory.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 293 Selected Topics in Physics Credits: 1 (1-0-0)**

**Course Description:** Selected topics in physics with emphasis on depth of understanding.

**Prerequisite:** PH 142.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 298 Introductory Research Credits: Var[1-6] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 314 Introduction to Modern Physics Credits: 4 (3-0-1)**

**Course Description:** Relativity; quantum mechanics; atomic structure; applications to solid-state, nuclear, and elementary particle physics.

**Prerequisite:** (MATH 261, may be taken concurrently or MATH 272, may be taken concurrently) and (PH 142).

**Registration Information:** Must register for lecture and recitation.

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 315 Modern Physics Laboratory Credits: 2 (0-4-0)**

**Course Description:** Experiments in modern physics.

**Prerequisite:** PH 314, may be taken concurrently.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 327 Analytical Techniques for Physics Credits: 3 (3-0-0)**

**Course Description:** Applications to physics of curvilinear coordinate systems, line/surface integrals, linear algebra, ordinary/partial differential eqs., probability.

**Prerequisite:** (MATH 261) and (MATH 340 or MATH 345) and (PH 142 and PH 314).

**Term Offered:** Fall.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 341 Mechanics Credits: 4 (4-0-0)**

**Course Description:** Particle dynamics, translation and rotation of rigid bodies, moving coordinate systems, Lagrangian mechanics, matrix and tensor methods.

**Prerequisite:** (MATH 340 or MATH 345) and (PH 141).

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 351 Electricity and Magnetism Credits: 4 (4-0-0)**

**Course Description:** Electrostatics, magnetostatics, currents, time-dependent electric and magnetic fields, radiation.

**Prerequisite:** (MATH 340 or MATH 345) and (PH 142).

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 353 Optics and Waves Credits: 4 (3-3-0)**

**Course Description:** Geometrical optics; wave optics; interference, diffraction, and polarization; quantum optics.

**Prerequisite:** MATH 261 and PH 142.

**Registration Information:** Must register for lecture and laboratory.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 361 Physical Thermodynamics Credits: 3 (3-0-0)**

**Course Description:** Laws of thermodynamics; thermodynamic potentials; applications such as fluids, phase transitions, electrical and magnetic systems, binary mixtures.

**Prerequisite:** MATH 261 and PH 142.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 384 Supervised College Teaching Credits: Var[1-5] (0-0-0)**

**Course Description:** Participation as a physics tutor.

**Prerequisite:** PH 121 or PH 141.

**Registration Information:** Written consent of department chair required.

A maximum of 10 combined credits for all 384 and 484 courses are counted towards graduation requirements.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 412 Quantum Optics for Quantum Info Science Credits: 4 (3-2-0)**

**Course Description:** Topics in the field of quantum optics which are relevant for quantum information science. Lectures are focused on the physics of the quantum behavior of light including concepts such as field quantization, coherent states, and quantum entanglement. The laboratory component focuses on tabletop experiments in quantum optics.

**Prerequisite:** PH 314.

**Registration Information:** Must register for lecture and laboratory.

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 425 Advanced Physics Laboratory Credits: 2 (0-4-0)**

**Course Description:** Advanced experiments in electricity and magnetism, statistical physics and quantum mechanics.

**Prerequisite:** PH 315 and PH 451.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 451 Introductory Quantum Mechanics I Credits: 3 (3-0-0)**

**Course Description:** Schrodinger's theory of wave mechanics, potential wells, harmonic oscillators, wave packets, operators, angular momentum.

**Prerequisite:** (MATH 272 or MATH 340 or MATH 345) and (PH 314 with a minimum grade of C).

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 452 Introductory Quantum Mechanics II Credits: 3 (3-0-0)**

**Course Description:** Approximation techniques, perturbation theory, identical particles and spin, structure and spectra of atoms and molecules, hydrogen atom.

**Prerequisite:** PH 451.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 462 Statistical Physics Credits: 3 (3-0-0)**

**Course Description:** Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein distribution functions; kinetic theory; applications to solids, metals, semiconductors, and gases.

**Prerequisite:** MATH 340 and PH 314 and PH 361.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 492 Seminar Credit: 1 (0-0-1)**

**Course Description:** Preparation and presentation of seminars on selected modern topics.

**Prerequisite:** PH 315.

**Registration Information:** Written consent of instructor required.

**Term Offered:** Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 495 Independent Study Credits: Var[1-6] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 498 Research Credits: Var[1-6] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 517 Chaos, Fractals, and Nonlinear Dynamics Credits: 3 (3-0-0)**

**Course Description:** Strange attractors, fractal dimensions, Lyapunov exponents, multifractal spectrum, period doubling, universality, intermittency, time-delay embedding.

**Prerequisite:** (MATH 261 and PH 341) and (MATH 340 or MATH 345).

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 521 Introduction to Lasers Credits: 3 (3-0-0)**

**Course Description:** Stimulated emission; laser resonators; theory of laser oscillation; specific laser systems; applications.

**Prerequisite:** (MATH 340 and PH 353) and (CHEM 476 or PH 451).

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 522 Introductory Laser Laboratory Credit: 1 (0-2-0)**

**Course Description:** Experiments providing hands-on experiences with lasers.

**Prerequisite:** PH 521, may be taken concurrently.

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 531 Introductory Condensed Matter Physics Credits: 3 (3-0-0)**

**Course Description:** Crystal structures and bonding, electronic levels and vibrations, dielectric, optical and magnetic properties, quasiparticles, superconductivity.

**Prerequisite:** PH 451 and PH 361.

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 561 Elementary Particle Physics Credits: 3 (3-0-0)**

**Course Description:** Particle interactions and detection techniques. Quark model, scattering models and standard model of electroweak interactions, physics of colliders.

**Prerequisite:** PH 451.

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 571 Mathematical Methods for Physics I Credits: 3 (3-0-0)**

**Course Description:** Vector analysis, eigenvalues and eigenvectors, infinite series, method of Frobenius, complex variables, contour integration.

**Prerequisite:** MATH 340.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 572 Mathematical Methods for Physics II Credits: 3 (3-0-0)**

**Course Description:** Partial differential equations, Sturm-Liouville theory, special functions, Green's functions, Fourier series, Fourier and Laplace transforms.

**Prerequisite:** PH 571.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 621 Classical Mechanics Credits: 3 (3-0-0)**

**Course Description:** Central forces, scattering, noninertial reference frames, Coriolis force, Lagrange's and Hamilton's equations, small oscillations, continuum mechanics.

**Prerequisite:** (PH 341) and (PH 571, may be taken concurrently).

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 631 Modern Topics in Condensed Matter Physics Credits: 3 (3-0-0)**

**Course Description:** Selected topics in modern condensed matter physics. Examples include topological phases of matter, superconductivity, heavy fermions, density functional theory, surfaces and interfaces.

**Prerequisite:** PH 531.

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Spring (every third year).

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 641 Electromagnetism I Credits: 3 (3-0-0)**

**Course Description:** Electrostatics in a vacuum and a medium, general solution of Laplace's equation, Green's functions, magnetostatics in a vacuum and a medium.

**Prerequisite:** (PH 351) and (PH 571).

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 642 Electromagnetism II Credits: 3 (3-0-0)**

**Course Description:** Maxwell's equations, electromagnetic waves, radiation by accelerated charges, special relativity, Lagrangian formulation of electromagnetism.

**Prerequisite:** PH 641.

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 651 Quantum Mechanics I Credits: 3 (3-0-0)**

**Course Description:** WKB theory, Heisenberg picture, 3D wells, hydrogen atom, time-independent perturbation theory, angular momentum and spin, Clebsch-Gordan coefficients.

**Prerequisite:** (PH 452) and (PH 571, may be taken concurrently).

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 652 Quantum Mechanics II Credits: 3 (3-0-0)**

**Course Description:** Wigner-Eckhart theorem, symmetries, density matrix, identical particles, interaction picture, time-dependent perturbation theory, scattering.

**Prerequisite:** PH 651.

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Spring.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 671 Statistical Mechanics Credits: 3 (3-0-0)**

**Course Description:** Canonical and grand-canonical ensembles; Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac statistics; density operator; Bose-Einstein condensation.

**Prerequisite:** (PH 452 and PH 462) and (PH 571, may be taken concurrently).

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 692 Seminar Credit: 1 (0-0-1)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 693 Current Topics in Physics Research Credits: 3 (0-0-3)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Term Offered:** Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 698 Research Credits: Var[1-18] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 699 Thesis Credits: Var[1-18] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 721 Advanced Atomic, Molecular, Optical Physics Credits: 3 (3-0-0)**

**Course Description:** Atomic and molecular structure, interaction of atoms and molecules with radiation, laser cooling, atomic and molecular traps, experimental design, and a survey of contemporary experiments.

**Prerequisite:** PH 652, may be taken concurrently.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Credit not allowed for both PH 721 and PH 780A1.

**Term Offered:** Spring (every third year).

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 722 Quantum Electronics Credits: 3 (3-0-0)**

**Course Description:** One- and two-photon spectroscopy; broadening mechanisms; nonlinear optics; coherent phenomena; experimental methods.

**Prerequisite:** PH 521.

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Spring.

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 731 Condensed Matter Theory Credits: 3 (3-0-0)**

**Course Description:** Second quantization; electrons; phonons; electron-phonon interaction; superconductivity; magnetism; spin waves; density-functional methods; symmetry.

**Prerequisite:** (PH 462) and (PH 531) and (PH 652).

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall (odd years).

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 762 Elementary Particle Theory Credits: 3 (3-0-0)**

**Course Description:** Symmetries, electrodynamics, renormalization, and the running coupling constant. Hadron structure, QCD, gauge symmetry and electroweak interaction.

**Prerequisite:** PH 561 and PH 652.

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall (even years).

**Grade Mode:** Traditional.

**Special Course Fee:** No.

**PH 770 Quantum Theory Credits: 3 (3-0-0)**

**Course Description:** Formal scattering theory; relativistic quantum mechanics, quantum theory of radiation, symmetries and statistics, many-body theory.

**Prerequisite:** PH 652.

**Restriction:** Must be a: Graduate, Professional.

**Term Offered:** Fall.

**Grade Modes:** S/U within Student Option, Trad within Student Option.

**Special Course Fee:** No.

**PH 784 Supervised College Teaching Credits: Var[1-5] (0-0-0)**

**Course Description:** Supervised teaching of general physics laboratory and recitation sections.

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 793A Seminar: Condensed Matter Physics Credits: Var[1-5] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 793B Seminar: Laser Spectroscopy/Quantum Electronics Credits: Var[1-5] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 793C Seminar: Statistical Mechanics Credits: Var[1-5] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 793D Seminar: Mathematical Physics Credits: Var[1-5] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 793E Seminar: High Energy Physics Credits: Var[1-5] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 795 Independent Study Credits: Var[1-6] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.

**PH 799 Dissertation Credits: Var[1-18] (0-0-0)**

**Course Description:**

**Prerequisite:** None.

**Restriction:** Must be a: Graduate, Professional.

**Registration Information:** Written consent of instructor.

**Terms Offered:** Fall, Spring, Summer.

**Grade Mode:** Instructor Option.

**Special Course Fee:** No.