Key to Course Listings

Catalog numbers are part of a University-wide numbering system. Generally, courses numbered 100 to 199 are introductory, 200-299 are intermediate, and 300-499 are advanced (upper-level).

Reorganized or renumbered courses are denoted by a parenthetical number in boldface following the course number. When renumbering or reorganization has left the SUBJECT unchanged, only the previous catalog number is given; if the SUBJECT has also changed, the previous SUBJECT name and course number appear. A reorganized or renumbered course cannot be repeated for credit without special permission.

Cross-listed courses are sponsored by more than one department or program and may be elected in any of the participating units. Cross-listings appear in boldface and are denoted by a slash between the participating units.

Course titles appear in boldface after the catalog number.

Prerequisites appear in italics after the course title. Some prerequisites are advisory. They suggest the assumed background or level of academic experience, and students should be guided by these statements. Some prerequisites are mandatory and are enforced at the point of registration. The *Course Guide* and the *LS&A Bulletin* indicate the cases when prerequisites are enforced.

Prerequisites are of three types:

- *Courses.* Unless otherwise stated, the phrase "or equivalent" may be considered an implicit part of the prerequisite for any course. When a student has satisfactorily completed a course(s) at the required level of competency and when that course is believed to be substantially equivalent to one listed as a prerequisite, the student must consult the instructor or department. If equivalency is determined to have been satisfied, election may be approved by issuance of electronic permission.
- *Class standing* (first year, sophomore, junior, senior). A course might be appropriate for "first and second year students only," or for "juniors and seniors."
- *Permission of instructor.* The phrase "or permission of instructor" may be considered an implicit part of the statement of prerequisites for any course. When permission is a stated requirement, or when a student does not have the stated prerequisite for a course but can give evidence of sufficient background, the student should obtain approval from the instructor or department concerned and an electronic permission issued.

The Credit Symbol, an Arabic numeral in parentheses, denotes the credits earned for the course. Credit is granted in semester hours. Except for small seminars where the reading and/or writing requirements are intensive, one credit represents no less than one hour of class meeting time each week of the term, and usually represents two hours of work outside of class for each class hour.

Area distribution designation is approved by the LS&A Curriculum Committee on a yearly basis. A course may be approved with the designation natural science *(NS),* social science *(SS),* humanities *(HU),* mathematical and symbolic analysis *(MSA),* creative expression *(CE),* interdisciplinary *(ID),* or excluded from distribution *(Excl).*

Courses meeting certain college requirements are so listed. Language other than English *(LR)* courses may be used toward meeting the Language Requirement. The First-Year Writing Requirement may be met by courses designated (Introductory Composition). Courses approved with the designation "Language Requirement" or "Introductory Composition" may not be used as part of an area distribution plan. If an introductory language course is designated "Excluded" *(Excl),* it may not be used to satisfy the LS&A language requirement. *(BS)* means that the course may be used toward the 60 approved credits required for the B.S. degree. Courses meeting or partially meeting the Quantitative Reasoning requirement are designated *(QR/1)* or *(QR/2).* Courses with standard approval for meeting the Race & Ethnicity *(R&E)* requirement are so indicated. Other courses may meet the R&E or QR requirements on a term-by-term basis and are listed on the LS&A website (http://www.lsa.umich.edu/).

Experiential, Independent Study, and Tutorial courses are so designated. (See Experiential and Directed Reading/Independent Study Courses in *Chapter IV.*)

Repetition of a course that varies in content from term to term is permitted only under certain conditions. When a department or program has a policy about the repetition of a course for credit, that policy is included in the course listing. The general statement "May be repeated for credit with permission" usually means "With permission of a concentration advisor." In all other instances, a student must get permission from both the department or program and the Academic Standards Board to repeat a course for credit. Generally, a course may be elected for credit once only.

Excluded combinations of course elections are designated in the listing of affected courses.

Special Grading pattern for a course is indicated in the course listing. Some LS&A courses are offered *mandatory credit/no credit.* (See Non-Graded Courses in *Chapter IV.*)

The Term Symbol, a Roman numeral, denotes the term(s) some courses are offered. The University year is divided into three terms: Fall (I), Winter (II), and Spring-Summer (III). The Spring-Summer Term is further divided: Spring-Half (IIIa) and Summer-Half (IIIb).

Courses That Count Toward Graduate Programs

Courses Approved for Regular Rackham Graduate Credit. All courses taken in fulfillment of Rackham degree requirements must be approved for Rackham graduate credit. Be certain that any courses you plan to take--especially those numbered in the 400s--are approved for Rackham credit before you enroll in them. The Graduate School policy on courses is as follows: Courses at the 400 level and above are acceptable for graduate credit if they have been approved by the Graduate School.

If you are uncertain whether or not a course is approved for Rackham credit, check with the department offering the course or with the Rackham Course Approval Officer (764-8221).

If you elect a course that has not been approved for Rackham graduate credit, the course will appear on your university transcript with the notation "Not for Graduate Credit. The course grade will appear on the transcript, but it will not be averaged into your cumulative grade point average or your credit toward program (CTP) total.

Courses Not Approved for Graduate Credit. Courses at the 300 level and below are not acceptable for graduate credit, without exception. Undergraduate level foreign language courses may occasionally be used in fulfillment of some departmental foreign language requirements.

Under unusual circumstances you may petition to receive graduate credit for a course not normally approved for graduate credit *(e.g.,* such as an undergraduate course where you will be expected to perform more advanced work than the undergraduates). Because there is no guarantee of approval, you should submit your petition to the Graduate School's Office of Academic Records and Dissertations (OARD) before taking the course. Your petition must be endorsed by the course instructor and by the graduate chair of your department or program, and it must include an explanation for requesting the exception. You will be expected to perform graduate level work in the course, and the petition must show how this will be accomplished. You may obtain a petition form from your department, from OARD, or online .

Physics

Physics

Physics PHYSICS 444

LSA
Physics
Physics

http://www.physics.lsa.umich.edu/

Undergraduate Courses

105 **PHYSICS 105.**
Origin, and Fate of Life, Stars, Galaxies, and the Universe.
(1,1) : May not be repeated for credit.
(NS). (BS).
II.
Origin and evolution of planets, stars, galaxies and the universe, and life in the universe.

106 **PHYSICS 106.**
Everyday Physics.
(3,3) : May not be repeated for credit.
(NS). (BS).
It is recommended that School of Education students take PHYSICS 420. Laboratory fee ($25) required.
This course examines everyday phenomena and current technology in terms of physical concepts and laws. The subjects examined are wide ranging and the discussion focuses on discovering common underlying themes.

107 **PHYSICS 107.**
20th-Century Concepts of Space, Time, and Matter.
(3,3) : May not be repeated for credit.
(NS). (BS). (QR/1).
High school algebra and geometry. I.
The course is intended to acquaint students with some of the most important conceptual developments in physics in the 20th century.

109 **PHYSICS 109 / CHEM 109.**
Natural Science: Bridging the Gaps.
(3) : May not be repeated for credit.
(NS). (BS).
An interdisciplinary, team-taught introduction to the scientific method, involving subject matter from physics, chemistry, astronomy, geology, biology, and ethics. Demonstrations provide nearly hands-on experience with relevant phenomena.

111 **PHYSICS 111.**
The Evolution of Scientific Thought.
(3) : May not be repeated for credit.
(NS). (BS). (QR/2).
High school algebra and trigonometry. Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor.
Traces the evolution of scientific thought from antiquity to the early 20th century. Emphasis on physics and astronomy, but selected topics in medicine, mathematics, biology, and chemistry are covered.

112 **PHYSICS 112.**
Cosmology: The Science of the Universe.
(3,3) : May not be repeated for credit.
(NS). (BS).
Although no science prerequisites are required, exposure to physics at high school level would be helpful. Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor. I.
What else is there in the universe besides stars? Why do we think there was a big bang? How big is a galaxy and how might they have formed? This course provides answers to such questions, stressing conceptual understanding and simple calculational problem solving.

119 **PHYSICS 119 / GEOSCI 130 / CHEM 108.**
The Physical World.
(4,4) : May not be repeated for credit.
(NS). (BS). (QR/2).
High-school algebra.
A lecture course which introduces physics, chemistry and algebraic concepts of Earth and Planetary Science on a quantitative basis.

125 **PHYSICS 125.**
General Physics: Mechanics and Sound.
(4,4) : May not be repeated for credit.
(NS). (BS). (QR/1).
Two and one-half years of high school mathematics, including trigonometry. PHYSICS 125 and 127 are normally elected concurrently. No credit granted to those who have completed or are enrolled in PHYSICS 135, 140 or 160. I, II, IIIa.
PHYSICS 125 is the first of a two-term sequence offered primarily for students concentrating in the natural sciences, architecture, pharmacy, or natural resources, and for preprofessional students preparing for medicine, dentistry or related health sciences. PHYSICS 125 and 126 are an appropriate sequence for any student wanting a quantitative introduction to the basic principles of physics but without the mathematical sophistication of PHYSICS 140 and 240. Strong emphasis is placed on problem solving, and skills in rudimentary algebra and trigonometry are assumed. While a high school level background in physics is not assumed, it is helpful. Topics covered during the first term include vectors, one- and two-dimensional motion, Newton's laws of motion, gravitation, rotational motion, momentum, energy, pressure in fluids, oscillations, and waves. The course is based on three one-hour examinations, class performance and a final examination. PHYSICS 125 students elect PHYSICS 127 (lab).

126 **PHYSICS 126.**
General Physics: Electricity and Light.
(4,4) : May not be repeated for credit.
(NS). (BS). (QR/1).
PHYSICS 125. PHYSICS 126 and 128 are normally elected concurrently. No credit granted to those who have completed or are enrolled in PHYSICS 235, 240 or 260. I, II, IIIa.
PHYSICS 126 is a continuation of PHYSICS 125 and covers electricity and magnetism, the nature of light, and briefly introduces atomic and nuclear phenomena. PHYSICS 126 students elect PHYSICS 128 (lab).

127 **PHYSICS 127.**
Mechanics and Sound Lab.
(1,1) : May not be repeated for credit.
(NS). (BS).
Concurrent election with PHYSICS 125 is strongly recommended. No credit granted to those who have completed or are enrolled in PHYSICS 141. Laboratory fee ($25) required. I, II, IIIa.
Laboratory course to be elected concurrently with PHYSICS 125. Meets two hours per week.

128 **PHYSICS 128.**
Electricity and Light Lab.
(1,1) : May not be repeated for credit.
(NS). (BS).
Concurrent election with PHYSICS 126 is strongly recommended. No credit granted to those who have completed or are enrolled in PHYSICS 241. Laboratory fee ($25) required. I, II, IIIa.
Laboratory course to be elected concurrently with PHYSICS 126.

135 **PHYSICS 135.**
Physics for the Life Sciences I.
(4) : May not be repeated for credit.
(NS). (BS). (QR/1).
MATH 115, 175, 185, or 195. Concurrent enrollment in PHYSICS 141. No credit granted to those who have completed or are enrolled in PHYSICS 125, 140, or 160.
This two-course sequence is an introduction to physics from the perspective of the life sciences. It introduces many of the physical processes which govern the workings of life, and teaches students how to analyze the physical circumstances of life in a quantitative way.

140 **PHYSICS 140.**

General Physics I.

(4,4) : May not be repeated for credit.

(NS). (BS). (QR/1).

MATH 115. PHYSICS 140 and 141 are normally elected concurrently. No credit granted to those who have completed or are enrolled in PHYSICS 125, 135 or 160. I, II, IIIa.

The traditional course format consists of two lectures and two discussions each week. However, there are Keller sections available which meet four hours each week in two-hour sessions. This is the first of a three-term sequence in general physics for scientists and engineers. Covers topics from classical mechanics, including vectors, motion in one dimension, circular motion, projectile motion, relative velocity and acceleration, Newton's laws, particle dynamics, work and energy, linear momentum, torque, angular momentum of a particle, simple harmonic motion, gravitation, planetary motion, pressure and density of fluids, and Archimedes principle.

141 **PHYSICS 141.**

Elementary Laboratory I.

(1,1) : May not be repeated for credit.

(NS). (BS).

Concurrent election with PHYSICS 140 or 160 is strongly recommended. No credit granted to those who have completed or are enrolled in PHYSICS 127. Laboratory fee ($25) required.

One two-hour period of laboratory work each week and designed to accompany PHYSICS 140.

160 **PHYSICS 160.**

Honors Physics I.

(4,4) : May not be repeated for credit.

(NS). (BS). (QR/1).

MATH 115. Students should elect PHYSICS 141 concurrently. No credit granted to those who have completed or are enrolled in PHYSICS 125, 135 or 140.

A rigorous introduction to particle mechanics and the motion of extended objects. Particular topics include vectors, one and two dimensional motion, conservation laws, linear and rotational dynamics, gravitation, fluid mechanics and thermodynamics.

204 **PHYSICS 204 / GTBOOKS 204.**

Great Books in Physics.

(4,4) : May not be repeated for credit.

(NS). (BS).

Study of selected works of Galileo, Newton, and Faraday.

235 **PHYSICS 235.**

Physics for the Life Sciences II.

(4) : May not be repeated for credit.

(NS). (BS).

MATH 115, 175, 185, or 195 with C or better (Prerequisites enforced at registration). Concurrent enrollment in PHYSICS 241. No credit granted to those who have completed or are enrolled in PHYSICS 126, 240, or 260.

This two-course sequence is an introduction to physics from the perspective of the life sciences. It introduces many of the physical processes which govern the workings of life, and teaches students how to analyze the physical circumstances of life in a quantitative way.

240 **PHYSICS 240.**

General Physics II.

(4,4) : May not be repeated for credit.

(NS). (BS). (QR/1).

PHYSICS 140 or 160; and MATH 116. PHYSICS 240 and 241 are normally elected concurrently. No credit granted to those who have completed or are enrolled in PHYSICS 126, 235 or 260. I, II, IIIa.

The traditional course format consists of two lectures and two discussions each week. However, there are Keller sections available which meet four hours each week in two-hour sessions. This is the second of a three-term sequence in general physics for scientists and engineers. The following topics are covered: electricity and magnetism: charge, Coulomb's law, electric fields, Gauss' law, electric potential, capacitors and dielectrics, current and resistance, EMF and circuits, magnetic fields, Biot-Savart law, Amperes law, Faraday's Law of Induction, and simple AC circuits.

241 **PHYSICS 241.**

Elementary Laboratory II.

(1,1) : May not be repeated for credit.

(NS). (BS).

Concurrent election with PHYSICS 240 or 260 is strongly recommended. No credit granted to those who have completed or are enrolled in PHYSICS 128. Laboratory fee ($25) required. I, II, IIIa.

One two-hour period of laboratory work each week and designed to accompany PHYSICS 240.

260 **PHYSICS 260.**

Honors Physics II.

(4,4) : May not be repeated for credit.

(NS). (BS). (QR/1).

PHYSICS 140 or 160; and MATH 116. Students should elect PHYSICS 241 concurrently. No credit granted to those who have completed or are enrolled in PHYSICS 126, 235 or 240.

A rigorous introduction to the theory of electromagnetic phenomena. Topics include electric and magnetic fields and potentials, DC and AC circuits, inductance and Maxwell's equations.

281 **PHYSICS 281.**

Physics and National Science Policy.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Junior standing; introductory physics courses preferred.

This course (1) addresses some of the contemporary issues affecting the environment in which physics education and research take place, and (2) reviews current major technical and policy challenges facing science. Additional emphasis on the issue of ethics in science and how unethical behavior impacts science and national policy.

288 **PHYSICS 288.**

Physics of Music.

(3,3) : May not be repeated for credit.

(NS). (BS). (QR/1).

No credit granted to those who have completed or are enrolled in PHYSICS 489. II.

The various connections between physics and music are explored: (1) The physics of musical sounds: vibrations, resonance, overtones, and musical scales; (2) The physics of the musical instruments: strings, winds, brass, percussion; (3) The physics of hearing, auditorium acoustics, and sound reproduction; (4) The depiction of physical events in music; (5) Analogies between the structure of music and the structure of physics. No previous expertise in either physics or music is required; lectures and demonstration experiments constitute the backbone of the course.

290 **PHYSICS 290.**

Physics of the Body and Mind.

(3,3) : May not be repeated for credit.

(NS). (BS). (QR/2).

PHYSICS 125 or 140 or 160 (Prerequisites enforced at registration).

Application of physics to biology, biochemistry, physiology, psychology, genetics, medicine, bioengineering, and related life sciences. Extensive A/V and CAI materials are used, provides an introduction to topics in biomechanics, biophysics, and medical physics including biosensors (EKG, EMG, ...) and imaging (X-rays, CT, PET, MRI, ultrasound, ...)

333 **PHYSICS 333.**

PHYSICS 140 Tutor.

(1-3,1-3) : May not be repeated for credit.

(Excl). (EXPERIENTIAL).

Consent of instructor required (Prerequisites enforced at registration). Offered mandatory credit/no credit.

Students enrolled in this experiential course serve as peer leaders in PHYSICS 140. Peer leaders conduct study group sessions under the direction of the course lecturer after receiving training from the staff at the Science Learning Center.

334 **PHYSICS 334.**

PHYSICS 240 Tutor.

(1-3,1-3) : May not be repeated for credit.

(Excl). (EXPERIENTIAL).

Consent of instructor required (Prerequisites enforced at registration). Offered mandatory credit/no credit.

Students enrolled in this experiential course serve as peer leaders in PHYSICS 240. Peer leaders conduct study group sessions under the direction of the course lecturer after receiving training from the staff at the Science Learning Center.

340 **PHYSICS 340.**

Waves, Heat, and Light.

(3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 240 or 260, and MATH 215 or 255 or 285 (Prerequisites enforced at registration). Concurrent election of PHYSICS 341 is strongly recommended.

This is the third term of the introductory physics sequence. The topics covered in the course include thermodynamics, light and optics, the wave equation, and special relativity. Students should take the lab PHYSICS 341 concurrently.

341 **PHYSICS 341.**

Waves, Heat, and Light Lab.

(2,2) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 240 or 260 (Prerequisites enforced at registration). Concurrent election of PHYSICS 340 is strongly recommended. Laboratory fee ($25) required.

This lab course accompanies PHYSICS 340. Six experiments are performed on topics such as temperature measurement, black body radiation, optics, interference, diffraction and the speed of light.

390 **PHYSICS 390.**

Introduction to Modern Physics.

(3,3) : May not be repeated for credit.

(Excl). (BS).

MATH 216 or 256 or 286 or 316 (Prerequisites enforced at registration).

This course provides an introduction to the principles of quantum mechanics, followed by a survey of several of the sub-fields of physics, usually including atomic, solid state, nuclear, and particle physics.

415 **PHYSICS 415.**

Special Problems for Undergraduates.

(1-6,1-6) : May be repeated for credit for a maximum of 6 credits.

(Excl). (INDEPENDENT).

Consent of instructor (Prerequisites enforced at registration).

Experimental or theoretical research under the supervision of a staff member. Generally a small facet of a large research undertaking is investigated in detail.

465 **PHYSICS 465.**

Senior Seminar.

(2,2) : May not be repeated for credit.

(Excl). (BS).

Junior or senior physics concentrators (Prerequisites enforced at registration). Meets the Upper-Level Writing Requirement.

Seminar dealing with selected topics of current physics designed to give physics concentrators an acquaintance with the principal fields of modern research.

496 **PHYSICS 496.**

Senior Thesis, I.

(2-3,2-3) : May not be repeated for credit.

(Excl). (BS). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Permission of departmental concentration advisor. Continuing Course. Y grade can be reported at end of the first-term to indicate work in progress. At the end of the second term (PHYSICS 497), the final grade is posted for both term's elections. I, II, III, IIIa, IIIb.

Students get introductory experience and research work with faculty, the results of which could provide the basis for a senior thesis project. If work is not completed in the Fall term, student would register for PHYSICS 497 in Winter term.

497 **PHYSICS 497.**

Senior Thesis, II.

(2-3,2-3) : May not be repeated for credit.

(Excl). (BS). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Permission of departmental concentration advisor. I, II, III, IIIa, IIIb.

A continuation of PHYSICS 496. Students who do not complete their thesis research in PHYSICS 496, may continue to PHYSICS 497. If continuing, a grade of Y is given for PHYSICS 496 and a final senior thesis grade given upon completion of the research.

498 **PHYSICS 498.**

Introduction to Research for Honors Students.

(2-3,2-3) : May not be repeated for credit.

(Excl). (BS). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Permission of departmental concentration advisor. Continuing Course. Y grade can be reported at end of the first-term to indicate work in progress. At the end of the second term (PHYSICS 499), the final grade is posted for both term's elections. I, II, III, IIIa, IIIb.

Honors students do research under the supervision of a faculty member. The results can provide a basis for an Honors thesis. If work is not completed during the Fall Term, the student must register for PHYSICS 499 in Winter Term.

499 **PHYSICS 499.**

Introduction to Research for Honors Students.

(2-3,2-3) : May not be repeated for credit.

(Excl). (BS). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Permission of physics concentration advisor. I, II, III, IIIa, IIIb.

Honors students do research under the supervision of a faculty member. The results can provide a basis for an Honors thesis.

Undergraduate and Graduate Courses

401 **PHYSICS 401.**

Intermediate Mechanics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS). (QR/1).

PHYSICS 126/128 or 240 (or 260)/241; and MATH 216 or 256 or 286 or 316 (Prerequisites enforced at registration).

Newtonian and Lagrangian mechanics: Kinematics and dynamics in one, two and three dimensions, vector analysis; motion under gravity, planetary motion; free and forced, damped and undamped harmonic oscillators; the conservation laws of mechanics; inertial and accelerated frames of reference, fictitious forces; rigid body mechanics; coupled oscillators.

402 **PHYSICS 402.**

Optics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 126/128 or 240 (or 260)/241; and MATH 216 or 256 or 286 or 316 (Prerequisites enforced at registration). A student can receive credit for only one of EECS 334 or PHYSICS 402. I.

The phenomena of physical optics, reflection, refraction, dispersion, interference, diffraction, and polarization interpreted in terms of the wave theory of light.

405 **PHYSICS 405.**

Intermediate Electricity and Magnetism.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 126/128 or 240(or 260)/241; and MATH 216 or 256 or 286 or 316 (Prerequisites enforced at registration). PHYSICS 340 recommended. Prior or concurrent enrollment in PHYSICS 451.

Emphasis is placed upon the basic physical principles including electrostatics, magnetostatics, time-dependent electromagnetic fields and the effect of fields on dielectric and magnetic media. An introduction to Maxwell's equations and electromagnetic radiation is included. Other topics may include AC circuits and superconductivity.

406 **PHYSICS 406.**

Statistical and Thermal Physics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 390 (Prerequisites enforced at registration).

Introduction to thermal processes including the classical laws of thermodynamics and their statistical foundations: basic probability concepts; statistical description of systems of particles; thermal interaction; microscopic basis of macroscopic concepts such as temperature and entropy; the laws of thermodynamics; and the elementary kinetic theory of transport processes.

411 **PHYSICS 411.**

Introduction to Computational Physics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 401 and MATH 216. Some familiarity with a computer language.

Introduction to techniques of computational physics with applications in optics, atomic, solid-state, nuclear and particle physics. Topics covered include motion in a force field, calculation of electric and magnetic fields, optical and ion-optical ray tracing, quantum-mechanical (QM) bound states (Schrödinger Equation) and QM barrier penetration and scattering.

413 **PHYSICS 413 / CMPLXSYS 541.**

Introduction to Nonlinear Dynamics and the Physics of Complexity.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 401 (Prerequisites enforced at registration). I.

An introduction to non-linear science with an elementary treatment from the point of view of the physics of chaos and fractal growth.

417 **PHYSICS 417 / CHEM 417.**

Dynamical Processes in Biophysics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

MATH 216 or 256 or 286 or 316; and PHYSICS 340 or CHEM 463 (Prerequisites enforced at registration).

The physical basis of diffusive processes in biology and biochemistry, and optical spectroscopic means for measuring its rates. Topics include: membrane electrical potentials, nerve impulses, synaptic transmission, the physics of chemoreception by cells, motion and reaction kinetics of membrane components, optical microscopy, visible and UV light absorption, fluorescence and phosphorescence, quasielastic light scattering, mathematics of random fluctuations, and chaotic processes in biology.

420 **PHYSICS 420.**

Living with Physics for Elementary Teachers.

(3,3;3,3) : May not be repeated for credit.

(Excl).

Elementary Education Concentrator (Prerequisites enforced at registration). No credit granted to those who have completed or are enrolled in PHYSICS 106. Laboratory fee ($25) required. II.

An introduction to basic ideas of physics as an experimental science.

435 **PHYSICS 435.**

Gravitational Physics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 390 and 401 (Prerequisites enforced at registration). I.

The Einstein theory of general relativity for gravitation is discussed with implications for astrophysical observations and cosmology. In particular, the experimental tests of general relativity in the past as well as the significance of pulsars, black holes, supernovae, cosmic background radiation and gravitational wave detection are described.

441 **PHYSICS 441.**

Advanced Laboratory I.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 390 and any 400-level PHYSICS course (Prerequisites enforced at registration). I.

This is an advanced laboratory course. A wide selection of individual experiments is offered. Students are required to select five experiments in consultation with the lab instruction. Experiments are to be selected from several different areas of physics.

442 **PHYSICS 442.**

Advanced Laboratory II.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 390 and any 400-level PHYSICS course (Prerequisites enforced at registration). II.

This is an advanced laboratory course. A wide selection of individual experiments is offered. Students are required to select five experiments in consultation with the lab instruction. Experiments are to be selected from several different areas of physics.

451 **PHYSICS 451.**

Methods of Theoretical Physics I.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

MATH 215 or 255 or 285; and MATH 216 or 256 or 286 or 316 (Prerequisites enforced at registration). I.

This course covers (1) vectors, fields, and differential operators; (2) vector spaces,

452 **PHYSICS 452.**

Methods of Theoretical Physics II.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 451 (Prerequisites enforced at registration).

Applications of matrix theory and vector and tensor analysis; boundary value problems; approximation and variational methods; applications from theory of analytic functions; Fourier series and integrals; eigenvalue problems; spherical harmonics; Bessel functions and other special functions of mathematical physics; and Green's functions. Other topics may include an introduction to integral equations or group theory, with applications to physical problems.

453 **PHYSICS 453.**

Quantum Mechanics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 390 (Prerequisites enforced at registration).

An introduction to quantum mechanics that emphasizes the description of physical situations in one-, two-, and three dimensions as they occur in atoms, molecules and nuclei.

455 **PHYSICS 455.**

Electronic Devices and Circuits.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 240 (or 260) and 241 (Prerequisites enforced at registration).

An introduction to DC and AC circuits; equivalence theorems; introduction to diodes, bipolar transistors (BJT), field effect transistors (J-FET, MOSFET, IGFET); transistor amplifiers (frequency and pulse response via circuit simulation with SPICE); transistors as switches; integrated circuits (operational amplifiers and logicgates); Computer based circuit testing.

457 **PHYSICS 457.**

Subatomic Physics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 453 (Prerequisites enforced at registration). II.

The course is an introduction to nuclear and elementary particle physics. Topics include (1) nuclear structure: binding energies, size and shape; angular momentum, parity, isopin, magnetic moments, electric quadrupole moments; models for the nucleus; (2) the quark model of elementary particles: the standard model; the neutron and proton; mesons; gluons; resonant states; (3) nuclear and particle decays: radioactivity; barrier penetration and alpha-particle decay; the weak interaction and beta-decay; electromagnetic transitions (4) nuclear and quark-quark interactions: basic properties of the strong force; scattering; reactions and reaction models; and (5) experimental techniques: interaction of charged particles, gamma-rays and neutrons with matter; particle and radiation detectors; accelerators. The basic elements of quantum mechanics are used.

460 **PHYSICS 460.**

Quantum Mechanics II.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 453 (Prerequisites enforced at registration). II.

Develops the quantum description of phenomena at the scale of atoms and molecules.

463 **PHYSICS 463.**

Introduction to Solid State Physics.

(3,3;3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 453 (Prerequisites enforced at registration). II.

Structure and physical properties of crystalline solids. Ionic crystals, free electron theory of metals, band theory of solids, effects of impurities and imperfections, and theories of magnetism. Introduction to the concept of phonons, polarons, plasmons, *etc.* Interaction of radiation with crystalline materials.

481 **PHYSICS 481 / PUBPOL 481.**

Physics and National Science Policy.

(3,3;3,3) : May not be repeated for credit.

(Excl).

Junior standing; introductory physics courses preferred. May not be included in a concentration plan in physics.

This course (1) addresses some of the contemporary issues affecting the environment in which physics education and research take place, and (2) reviews current major technical and policy challenges facing science. Additional emphasis on the issue of ethics in science and how unethical behavior impacts science and national policy.

Graduate Courses

489 **PHYSICS 489.**

Physics of Music.

(3,3;3,3) : May not be repeated for credit.

(Excl). (QR/1).

Permission of instructor. No credit granted to those who have completed or are enrolled in PHYSICS 288. May not be included in a concentration plan in physics.

This course includes all material covered in PHYSICS 288 and, in addition, a theoretical or experimental project in which student works independently.

501 **PHYSICS 501.**

First-Year Mini-Colloquium.

(1) : May be elected twice for credit.

(Excl).

Graduate standing. This course has a grading basis of "S" or "U."

Course objective is to learn about research opportunities within the Physics graduate studies program.

505 **PHYSICS 505.**

Electricity and Magnetism I.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

Electrostatics, time-independent magnetic phenomena, time-dependent electromagnetic fields, free electromagnetic fields, covariant formalism of electrodynamics, scattering and diffraction of electromagnetic waves, wave guides, radiating systems, radiation from moving charges.

506 **PHYSICS 506.**

Electricity and Magnetism II.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

Electrostatics, time-independent magnetic phenomena, time-dependent electromagnetic fields, free electromagnetic fields, covariant formalism of electrodynamics, scattering and diffraction of electromagnetic waves, wave guides, radiating systems, radiation from moving charges.

507 **PHYSICS 507.**

Theoretical Mechanics I.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

Lagrangian and Hamiltonian formulations, symmetry and conservation laws, central force, rigid body motion, canonical transformations, Hamilton-Jacobi theory, perturbation theory.

508 **PHYSICS 508 / CMPLXSYS 535.**

Theory of Social and Technological Networks.

(3) : May not be repeated for credit.

(Excl). (BS).

Calculus and linear algebra; some computer programming experience recommended.

Introduces and develops the mathematical theory of networks, particularly social and technological networks; with applications to important network-driven phenomena in epidemiology of human infections and computer viruses, cascading failure in grids, network resilience and opinion formation. Topics covered: experimental studies of social networks, WWW, internet, information, and biological networks.

510 **PHYSICS 510.**

Statistical Physics I.

(3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 406 and graduate standing.

Review of thermodynamics, statistical bases of second law, entropy and irreversibility, equipartition, the Gibbs paradox. Quantum statistics, ideal Fermi gas, ideal Bose gas, Bose-Einstein condensation, phase equilibrium, phase transitions, fluctuations and transport theory.

511 **PHYSICS 511.**

Quantum Theory and Atomic Structure, I.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

This is a two-term sequence on the quantum theory and its applications to non-relativistic atomic, molecular, nuclear and solid state systems; time independent and time dependent perturbation theory; angular momentum, scattering theory; interaction of photons with non-relativistic systems; the Dirac equation.

512 **PHYSICS 512.**

Quantum Theory and Atomic Structure, II.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

This is a two-term sequence on the quantum theory and its applications to non-relativistic atomic, molecular, nuclear and solid state systems; time independent and time dependent perturbation theory; angular momentum, scattering theory; interaction of photons with non-relativistic systems; the Dirac equation.

513 **PHYSICS 513.**

Advanced Quantum Mechanics I.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

Introduction to the methods of relativistic quantum field theory with applications relevant to high energy and many body physics. Topics include: Feynman diagrams, calculation of cross sections for simple processes in scalar and spinor field theories, and the electron gas problem.

515 **PHYSICS 515.**

Supervised Research.

(4-6,4-6) : May not be repeated for credit.

(Excl). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Graduate standing. Permission of instructor required. This course has a grading basis of "S" or "U."

Four to six credit-hour courses in research.

516 **PHYSICS 516.**

Supervised Research.

(4-6,4-6) : May not be repeated for credit.

(Excl). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Graduate standing. Permission of instructor required. This course has a grading basis of "S" or "U."

Four to six credit-hour courses in research.

518 **PHYSICS 518 / APPPHYS 518.**

Microcomputers in Experimental Research.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

A laboratory course designed to give students hands-on experience with modern techniques of data acquisition, handling, and analysis, and graphical presentation of results using micro-computers. Several experiments will be carried out which illustrate how to interface research instrumentation in a variety of commonly encountered laboratory situations.

520 **PHYSICS 520.**

Condensed Matter Physics.

(3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 510, 511, and graduate standing.

Modern theory of solids with emphasis on electron states, band theory, electron-electron interactions, phonons, electron-phonon interactions, transport theory, semiconductor physics and superconductors.

521 **PHYSICS 521.**

Elementary Particle Physics I.

(3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 512 and graduate standing.

Overview for anyone who wants to understand the very successful "Standard Model" of particle physics, with emphasis on the predictions and tests of the theory, why it is now widely believed to describe nature, and also on open questions. Topics to be studied: the ElectroWeak theory and Quantum Chromodynamics, properties of quarks and leptons, Higgs bosons, CP violation, a few topics beyond the Standard Model (grand unifications, supersymmetry, and neutrino masses), and existing and future experimental facilities and detectors.

522 **PHYSICS 522.**

Atomic Physics and Quantum Mechanics.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

The structure of atoms and the interaction of atoms with fields. Topics: non-relativistic and relativistic hydrogen and positronium; Lamb shift; hyperfine interactions; group theory and the structure of multiple-electron atoms; coupling schemes; Hartree-Fock theory; single- and multi-channel quantum-defect theories; atoms in external fields; atomic transitions; linewidth; photoionization; strong-field effects; time reversal; parity violation; quantum chaos.

523 **PHYSICS 523.**

Advanced Quantum Mechanics II.

(3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 513 and graduate standing.

Advanced course in relativistic quantum field theory with emphasis on gauge field theories. Among the topics explored are renormalization and unitarity of abelian and non-abelian gauge theories, spontaneous symmetry breaking, and renormalization group.

525 **PHYSICS 525.**

Intro Topics in Astrophysics.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

Presentation of the standard model of cosmology, the Hot Big Bang model, development of the parameters of an expanding universe, and illustration of the three types of Friedmann Robertson Walker universes and the thermal history of the universe from its hot early stages through the epoch of recombination.

526 **PHYSICS 526.**

Intro Topics in Astrophysics II.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

527 **PHYSICS 527.**

Intro Topics in Astrophysics III.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

529 **PHYSICS 529 / APPPHYS 529.**

Techniques of Experimental Physics.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

The goal of this course is to get you acquainted with the concept of modern physics experiment and to help you learn important experimental skills and data analysis techniques. Apart from developing an appreciation of experimental approaches used in many areas of modern physics you will also gain
familiarity with:
Finding and studying previously published results and references;
Designing experimental procedures;
Choosing adequate instruments;
Observing and measuring physical phenomena;
Performing statistical analysis of the data with understanding of statistical and systematic errors;
Documenting experimental procedures;
Reaching conclusions and publishing experimental results;
Presenting your results in public.

540 **PHYSICS 540 / APPPHYS 601.**

Advanced Condensed Matter.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing.

A unified description of equilibrium condensed matter theory (using Green's functions); critical phenomena, Anderson localization and correlated electron theory.

541 **PHYSICS 541.**

Elementary Particle Physics II.

(3,3) : May not be repeated for credit.

(Excl). (BS).

PHYSICS 521. Graduate standing.

This course will take several topics from Particle Physics I (PHYSICS 521) and develop them in the detail appropriate for students planning to work in particle physics. Will include predictions and tests of the electroweak theory, QCD, supersymmetry, and CP violation.

542 **PHYSICS 542 / EECS 638.**

Quantum Optics.

(3,3) : May not be repeated for credit.

(Excl). (BS).

Graduate standing. CAEN lab access fee required for non-Engineering students.

Details of image formation theory, including the consideration of dynamic image sequences. The theoretical frameworks for edge detection, feature extraction, and surface description are presented. The relationship between image formation and object features is examined in detail. Programming required.

608 **PHYSICS 608 / BIOPHYS 608 / MCDB 608.**

Biophysical Principles of Microscopy.

(3,3) : May not be repeated for credit.

(Excl).

Knowledge of complex exponential notation, and graduate standing.

This course covers the physical, mathematical, and instrumental principles behind the major optical microscopy techniques used in modern cell biology and biochemistry. Included are bright field, dark field, phase contrast, differential interference, interference reflection, polarization, fluorescence labeling and detection, total internal reflection, schlieren, confocal, multiphoton, fluorescence resonance energy transfer, fluorescence lifetime, and CCD imaging techniques, as well as photobleaching, fluorescence temporal and spatial correlation spectroscopy and 3D image deconvolution image analysis. A familiarity with complex exponent mathematics to represent waves and some familiarity with basic geometrical and physical optics is highly beneficial. This course emphasizes the theoretical principles and practical applications rather than a "hands-on how-to-do-it" approach.

611 **PHYSICS 611 / APPPHYS 611 / EECS 634.**

Nonlinear Optics.

(3,3) : May not be repeated for credit.

(Excl).

EECS 537 or 538 or 530. Graduate standing. CAEN lab access fee required for non-Engineering students.

Formalism of wave propagation in nonlinear media; susceptibility tensor; second harmonic generation and three-wave mixing; phase matching; third order nonlinearities and four-wave mixing processes; stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fibers, including solitons and self-phase modulation.

619 **PHYSICS 619 / APPPHYS 619.**

Advanced Solid State Physics.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

After a review of semiconductor physics, the course will focus on quantum transport in semiconductor heterostructures. Topics such as electronic structure of III-V semiconductors, heterojunctions and band gap engineering, quantum wells, superlattices, resonant tunneling structures, two-dimensional electron gas, quantum point contacts, quantum dots and other mesoscopic structures, ballistic transport, coherent transport, and integer and fractional quantum Hall effects will be covered.

620 **PHYSICS 620.**

Solid State.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

An advanced course in condensed matter physics. It provides an introduction to basic subjects not covered in PHYSICS 520 *(e.g.,* linear response and group theory) as well as a presentation of topics of current interest such as the quantum Hall effect and superconductivity.

621 **PHYSICS 621.**

Quantum Theory of Fields.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

624 **PHYSICS 624.**

Advanced Statistical Methods.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

This course provides a practical introduction into the use of probability and statistics in experimental physics. The emphasis is on applications and understanding. The skills learned here are some of the basic skills physicists use wherever they are employed: industry, academia... The areas emphasized are rather different than those emphasized in mathematics department courses.

627 **PHYSICS 627.**

Experimental High Energy Physics.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

PHYSICS 627 will cover:

experimental techniques and results in High Energy Physics

experimental techniques and results in Accelerator Physics which involves the proton and electron accelerators and storage rings, which produce the MeV to GeV to TeV particles for these experiments.

628 **PHYSICS 628.**

Experimental Collider Physics.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

The course will cover techniques and physics of modern hadron collider experiment. Specifically, it will be organized in the following six main areas: collider detector, quantum chromodynamics, electroweak physics, to quark production and decays, B physics, and physics beyond the standard model.

629 **PHYSICS 629 / CHE 629.**

Complex Fluids.

(3,3) : May not be repeated for credit.

(Excl).

CHE 527. Graduate standing. CAEN lab access fee required for non-Engineering students.

Structure, dynamics, and flow properties of polymers, colloids, liquid crystals, and other substances with both liquid and solid-like characteristics.

635 **PHYSICS 635.**

Theory of Relativity.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

the route to general relativity, from the Minkowski space (the Gupta-Feynman approach), from gauge theories (the Uchiyama-Veltman approach), and from string theories;
the solutions of the Einstein Equation, with metrics (Schwartzschild, Kerr, ...) derived following the methods from Chandrasekhar's book;
the structure of black holes, with a focus on the mathematical structure using the Penrose diagram; and
astrophysics and cosmology, including gravitational lensing, gravitational waves, quasars, the expanding universe (the Friedman Solution and Hubble's Law), and cosmic background radiation.

644 **PHYSICS 644 / APPPHYS 644.**

Advanced Atomic Physics.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing.

Laser atom interactions: Absorption, emission, and saturation, theory of line width, multiphoton absorption, stimulated and spontaneous Raman scattering; single photon, multiphoton and above-threshold ionization; Rydberg physics; AC stark shifts and ponderomotive effects; multichannel quantum defect theory; Floquet theory; Mechanical effects of light on atoms (atom traps, molasses), atom interferometry.

645 **PHYSICS 645.**

An Introduction to M-Theory.

(3) : May not be repeated for credit.

(Excl).

Graduate standing. This course has a grading basis of "S" or "U."

This course provides an elementary introduction to M-Theory, a new non-perturbative theory which subsumes all five consistent string theories and whose low energy limit is eleven-dimensional supergravity.

646 **PHYSICS 646.**

String Theory.

(3) : May not be repeated for credit.

(Excl).

Knowledge of general relativity and introductory quantum field theory. This course has a grading basis of "S" or "U."

An introduction to the quantum theory of relativistic strings and its modern applications. Focus is on perturbative techniques based on conformal field theory in two dimensions. Important examples are D-branes, toroidal compactification and orbifolds. The course provides the foundation needed for applications of string theory to strongly gravitating systems such as black holes and cosmology as well as to particle physics.

650 **PHYSICS 650 / APPPHYS 550 / EECS 538.**

Optical Waves in Crystals.

(3,3) : May not be repeated for credit.

(Excl). (BS).

EECS 434. Graduate standing. CAEN lab access fee required for non-Engineering students.

Propagation of laser beams: Gaussian wave optics and the ABCD law. Manipulation of light by electrical, acoustical waves; crystal properties and the dielectric tensor; electro-optic, acousto-optic effects and devices. Introduction to nonlinear optics; harmonic generation, optical rectification, four-wave mixing, self-focusing, and self-phase modulation.

651 **PHYSICS 651 / APPPHYS 551 / EECS 539.**

Lasers.

(3,3) : May not be repeated for credit.

(Excl). (BS).

EECS 537 or 538. Graduate standing. CAEN lab access fee required for non-Engineering students.

Complete study of laser operation: the atom-field interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain and saturation; laser oscillation; laser resonators, modes, and cavity equations; cavity modes; laser dynamics, Q-switching and mode-locking. Special topics such as femto-seconds lasers and ultrahigh power lasers.

667 **PHYSICS 667.**

Advanced Astrophysics.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

668 **PHYSICS 668.**

Advanced Astrophysics.

(3,3) : May not be repeated for credit.

(Excl).

Graduate standing and permission of instructor.

690 **PHYSICS 690.**

Special Topics in Physics.

(3) : May be elected up to three times for credit.

(Excl).

Graduate standing. This course has a grading basis of "S" or "U."

Special topics taught by visiting scholars and/or visiting professors who wish to teach graduate level courses that currently do not exits. The content varies from term to term.

715 **PHYSICS 715.**

Special Problems.

(1-6,1-6) : May not be repeated for credit.

(Excl). (INDEPENDENT).

Consent of instructor required (Prerequisites enforced at registration). Graduate standing and permission of instructor.

Non-thesis research under the supervision of Physics faculty.

990 **PHYSICS 990.**

Dissertation/Precandidate.

(1-8,1-4) : May be repeated for credit.

(Excl). (INDEPENDENT).

Election for dissertation work by doctoral student not yet admitted as a Candidate. Graduate standing. This course has a grading basis of "S" or "U."

Election for dissertation work by doctoral student not yet admitted as a Candidate.

993 **PHYSICS 993.**

Graduate Student Instructor Training Program.

(1,1) : May not be repeated for credit.

(Excl).

Must have Teaching Assistant award. Graduate standing and permission of instructor. This course has a grading basis of "S" or "U."

A seminar for all beginning graduate student instructors, consisting of a two day orientation before the term starts and periodic workshops/meetings during the Fall Term. Beginning graduate student instructors are required to register for this class.

995 **PHYSICS 995.**

Dissertation/Candidate.

(8,4) : May be repeated for credit.

(Excl). (INDEPENDENT).

Graduate School authorization for admission as a doctoral Candidate (Prerequisites enforced at registration). This course has a grading basis of "S" or "U."

Graduate School authorization for admission as a doctoral Candidate. N.B. The defense of the dissertation (the final oral examination) must be held under a full term Candidacy enrollment period.