A 21st Century Curriculum for Undergraduate Physics Majors at Vanderbilt University

Executive Summary
November 8, 2016

In this report, the faculty of the Department of Physics & Astronomy present a revised curriculum for undergraduate Physics majors at Vanderbilt. The recommended changes represent a significant transition toward a curriculum appropriate for students of today. They formalize an approach to the physics major that is appropriate for the breadth of post-graduate options Vanderbilt Physics majors now pursue, including preparation for a PhD in Physics, Astronomy and related fields, and also for a wide range of professional career paths outside of academia. Finally, this new major establishes an option for physics majors to complete their Immersion Experience within the intellectual and academic context of the Department of Physics and Astronomy.

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Proposal

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I. Introduction

The faculty of the Department of Physics & Astronomy has examined the current structure of the Physics major and believes the time has arrived for making significant changes in the requirements for students pursuing this major. The faculty last implemented a significant revision of the Physics major in 1995. Since that time, the academic skills of entering first-year students at Vanderbilt have improved dramatically, the nature of physics has evolved rapidly toward including computation as a critical tool and many important topical areas of physics (e.g., biophysics, nanophysics, dark matter and dark energy, computer simulations, big data) have matured or gained much greater importance within or been introduced to the discipline. As a result, our 1995 curriculum no longer matches what is best for our students. In addition, Vanderbilt University now emphasizes more strongly the role of research in the educational mission of Vanderbilt University for our undergraduates. With this proposal, we intend to modernize our curriculum, match it more appropriately to twenty-first-century physics and the talents of the current and coming generations of Vanderbilt undergraduates and emphasize the Immersion Experience approach of Vanderbilt University.

Among the most important changes we must recognize and address are these:

1. About one-third of physics majors earn AP credit and skip over first-year physics, even though this is only possible if they matriculate with scores of 5 on three difficult AP exams: AP Physics C Mechanics, AP Physics C Electricity & Magnetism, and AP Calculus BC. When we implemented the 1995 curriculum, no matriculating students did this. We need to do a better job with the students who skip first-year physics.

2. With AP credit, students receive credit for two lecture courses (1601, 1602) and the associated labs (1601L, 1602L). The students with AP credit have strong backgrounds in the content areas taught in AP Physics (Mechanics and E&M) and also the mathematical skills needed to successfully start their study of physics at the sophomore level (nominally PHYS 2250). Very few of these students, however, have had strong laboratory preparation in high school. The students who have AP credit in physics do not take the first-year laboratory courses that are attached to the 1501/1601/1901 and 1502/1602/1902 lecture courses. As a result, they miss the courses in which we teach important lab skills and are often poorly prepared for the laboratory work associated with our more advanced laboratory classes. We wish to correct this problem.

3. A decade ago, 90% of our graduating physics majors went on immediately to pursue a PhD in physics, astronomy or engineering. Now, fewer than 15% follow this path. The other 85% are being hired as consultants or software designers, or they are going to professional school (medical, dental, law, business) or into pre-college teaching or the military (usually via ROTC). We would like to continue to send our best students to the best PhD programs, but we also need to ensure that our major supports the interests and goals of all of our majors.

4. Computational tools are much more important now for physics research; in addition, computational skills are invaluable in preparing physics majors for careers outside of academia.

5. The Immersion Experience is part of the future for all undergraduates at Vanderbilt. We want to offer physics majors an option of completing their Immersion Experience within the boundaries of a redefined Physics major.
II. The 1995 Curriculum in a Nutshell

1. 32-33 total credit hours (depending on choice for second-semester physics course).
2. First-year courses prerequisite to the major: first-semester calculus-based physics, with lab.
3. First-year courses required for the major: second-semester, calculus-based physics, with lab.
4. Upper-level courses required for the major: five core courses, two of which (2250, 2260) include laboratory components; the other three are a) Classical Mechanics (2270), b) Thermal and Statistical Physics (3200), and c) Electricity, Magnetism and Electrodynamics (2290).
5. Seminars required for the major: two one-credit seminars (one in Astronomy [ASTR 3000]; one in Physics [PHYS 3600]).
6. Coursework also required for the major: nine-credit hours of electives, at least one-third of which must be from a traditional course (i.e., no more than 6 credit hours of research).
7. Math background assumed via pre-reqs but not formally required: single and multivariable calculus.
8. Computer Science coursework assumed or required for the major: none.

III. Significant Proposed Changes

The following identifies significant changes we intend to make from the current program:

- Both semesters of first-year physics will be prerequisite to the major.
- All 2000-level and higher PHYS courses will assume CS 1101 and MATH 1300 and 1301 as prerequisites and MATH 2300 as a co/prerequisite.
- The third-semester course 2250 will be retitled “Modern Physics and the Quantum World” to better reflect its revised content and renumbered (2255), since it will be decoupled from the currently-associated lab. The lecture (2255) and lab (2953L) will become separate courses. The new title represents an evolution but not a complete re-invention of this course, including the expansion of special relativity content. This course will no longer satisfy the upper-level ‘W’ course requirement of AXLE, because the lab will become a stand-alone one-credit course (W courses must be three-or-more-credit courses).
- The lab components of 1901/1902/2250/2260 will be separated from the lecture courses to create a pedagogically-sound and required three-semester laboratory program, for which AP credit does not apply. The 1901 lab will be numbered as 1912L (the “1912” is designed to match the “1912 lecture course students should take at the same time); the 1902 lab will be numbered as 2255L (the “2255” is designed to match the 2255 lecture course the students should take at the same time). The content of these two labs will not change. Aspects of the 2250 and 2260 labs will be compressed into a single-semester course (2953L), Introduction to Experimental Research. The new three-semester lab sequence will begin in the second semester and continue through the fourth semester. This plan is designed to create space in the first semester for potential physics majors to take CS 1101.
- Statistical Physics (3200) will be renamed (no longer “Thermodynamics and Statistical Physics”). This more properly identifies what we teach and eliminates the perception of overlap between this course and “Thermodynamics” (ME 2220) taught in the School of Engineering.
- The most important concepts in Classical Mechanics I (2700) and Classical Mechanics II (2701) will be combined into a single-semester course (2755). Special Relativity, which has been taught in this two-semester sequence, will be dropped entirely from the new course but will be taught in 2255.
- The core will include five courses: Modern Physics and the Quantum World (2255), Classical Mechanics (2755), Electricity, Magnetism and Electrodynamics (2290), Statistical Physics (3200), and Quantum Mechanics (3651). Students will have the option of taking any four of the five courses in the core. This should encourage but not require more students to take Quantum Mechanics.
- Classical Mechanics (2275) will be moved to the Fall semester.
- Statistical Physics (3200) will be moved to the Spring semester, in order to encourage more students to take 2275 before (rather than at the same time as) 3200.
- Electricity, Magnetism and Electrodynamics will be retained as a two-semester sequence (2290, 2291) but we will shift it to become a fall-spring (rather than spring-fall) sequence.
With these scheduling adjustments, four of the core courses will have a natural sequence: Modern Physics and the Quantum World (2255) in the 3rd semester, Classical Mechanics (2275) in the 4th semester, Electricity, Magnetism and Electrodynamics I (2290) in the 5th semester course, and Statistical Physics (3200) in the 6th semester course.

Computational Physics (now 2237) will be revised to become a more advanced, capstone course (3790) and will be required as part of our major and as part of the Capstone in Physics portion of the major.

We wish to offer our most advanced majors the option of taking a ‘Mathematical Methods in Physics’ course; however, rather than invent a separate course for undergraduates, we will create an undergraduate course number (4005) for ‘Mathematical Methods of Physics’ to encourage and more easily enable our most advanced undergraduate majors to take the graduate version of this course (8005).

All physics majors will be required to do one semester of research as part of the Capstone in Physics portion of the major. This is not a radical change since more than 90% of our physics majors already do some research.

We will increase the number of elective hours to nine credit hours, not including research. This will both increase the rigor of the physics major and help increase enrollments in upper-level electives, some of which have ongoing problems with low enrollment numbers.

Many courses will have revised pre/coreqs; along with improved communication in the catalog and on our website, both students and faculty will clearly understand the order in which faculty expect students to take the core courses.

We will eliminate the ASTR 2600 one-credit seminar.

We will change the structure of the PHYS 3600 one-credit seminar. We will link it to the department’s colloquium program, include it as part of the Capstone in Physics portion of the major, and focus training students on effectively making presentations of research results.

We propose to create a zero credit-hour research course (3852) that will allow students to receive credit on their transcripts for intensive research done in the summer, either on or off campus.

IV. Requirements of the Proposed New Program

The requirements of the proposed new major in physics include 31-32 credit hours in the Department of Physics and Astronomy (depending on how a student navigates their path through the laboratory sequence).

An Introductory Physics lecture-course sequence equivalent to any of the following courses, is pre-requisite to the formal requirements of the major in Physics:

a. 1501, 1601, 1911 or 2051
b. 1502, 1602, 1912 or 2053

Students pursuing the major in Physics are also expected to have working knowledge in advanced mathematics and basic knowledge in computer programming. Those expectations are detailed in the proposed new catalog description for the Physics program and our expectations will be very clear to potential physics majors. We will not, however, impose formal course requirements in these content areas for the major in physics, as many of our students either have this background before matriculating at Vanderbilt or learn these skills outside of regular classroom work. Students without the necessary courses on their transcript may appeal to the Director of Undergraduate Studies for permission to enroll in upper level courses for which they lack the formal pre-requisite.

The formal requirements for the major in Physics are the following:

1. Four-course core (12 credit hours) chosen from the following five three-credit courses:
   a. Modern Physics and the Quantum World (2255) (Fall, Sophomore year).
   b. Classical Mechanics (2275) (Spring, Sophomore year).

1 2051 is used to award transfer credit for a rigorous first-semester, non-calculus-based physics course. It is primarily used for pre-college credit for students who earn a high enough score on the A-level exam for physics.
2 2053 is used to award transfer credit for a rigorous second-semester, non-calculus-based physics course. It is primarily used for pre-college credit for students who earn a high enough score on the A-level exam for physics.
c. Electricity & Magnetism I (2290) (Fall, Junior year).
d. Statistical Physics (3200) (Spring, Junior year).
e. Quantum Mechanics I (3651) (Spring, Junior or Senior year).

2. Three-semester laboratory core (3 or 4 credit hours)
a. 1912L (Spring, first year), or either 1501L or 1601L and either 1502L or 1602L
b. 2255L (Fall, Sophomore year).
c. 2953L (Spring, Sophomore year).

3. 9 credit hours of course work electives chosen from
   a. any 2000-level or higher courses offered by the Department.
   b. and/or any 2000-level or higher courses in science and/or engineering taught outside of the
      Department of Physics & Astronomy that are approved by the Director of Undergraduate Studies
      on a case-by-case basis (e.g., EES 4760 Physics of the Climate System).

4. Capstone in Physics (7 credit hours):
a. Computational Physics (3790) (Fall semester, Junior or Senior year).
b. Three credit hours of research (3850, 3851 or 4998).
c. Seminar in Presenting Physics Research (3600); (Fall or Spring, Junior or Senior year).

V. The Immersion Experience in Physics or in Astronomy

All Vanderbilt undergraduates, beginning with the entering cohort in Fall 2018, must complete an “Immersion
module” as a graduation requirement. We have designed the Immersion in Physics program such that the Immersion Experience may be part of their major but a student will not be required to complete an Immersion Experience in
the Physics major in order to complete a major in Physics. The College of Arts & Science has proposed the
following basic structure for Immersion Experiences completed directly under the supervision of A&S faculty:
The immersion module will consist of a group of activities and/or courses that cohere around a theme and
include the production of a significant original work. Immersion modules will normally comprise about 9
credits or their approximate equivalent and may include a mix of courses and non-credit activities, such as
relevant internships.

We are proposing a formal mechanism for physics majors that matches the intended goals of the faculty of our
College for the Immersion Experience.

The Department of Physics & Astronomy will offer a pre-defined path for completing the Immersion Experience within the disciplines of Physics and Astronomy through an enhanced version of the Capstone in Physics program. This Immersion Experience enhances students’ abilities in the three pillars of physics research at an
advanced level — experiment, theory and computation — and requires students to achieve a high level of
sophistication in their ability to present their research to others.

The Immersion Experience in Physics or in Astronomy can be completed as follows (9 credit hours):
  1. Introduction to Experimental Research (2953L) (1 credit hour)
  2. Seminar in Presenting Physics Research (3600), taken twice (2 credit hours).
  3. Research (3851, 4998) in physics and/or astronomy (3 credit hours).
  4. Computational Physics (3790) (3 credit hours).

The second time that a student takes PHYS 3600 (note: this course is only required to be taken once for the Physics
major), they will be required to make both oral and poster presentations of their own research results, in addition to
listening to and critiquing the presentations made by other candidates for the Immersion Experience in Physics or in
Astronomy.

Note that a student may complete the physics major by taking PHYS 3850 or ASTR 3850 for their research credits,
but can only obtain credit for the Immersion Experience in Physics or in Astronomy by choosing, instead, PHYS
3851 or 4998 or ASTR 3851 or 4998. Whereas the 3850 research course merely requires a student to be involved in
research (e.g., taking data, doing calculations, writing code and analyzing data), the 3851 and 4998 research classes
require a student to make an end-of-semester oral presentation or craft an end-of-project written report. The
Computational Physics class includes a Capstone project, which can be developed to complement the student’s
Immersion research.
Note also that a student may complete the Immersion Experience in Physics or in Astronomy by only completing six formal hours of research, if they satisfy the research requirement through either of the zero-credit hour courses ASTR 3852 or PHYS 3852.

VI. The Required Laboratory Program

All physics majors will be required to take a three-semester (three total credit hours) sequence of laboratory work. Students may not use AP credit to exempt themselves from taking any of these required laboratory courses.

The primary goal of the first two revised, stand-alone laboratory classes (1912L; 2255L) is to teach students fundamental laboratory skills. Learning physics, which will happen because they will do physics experiments as a vehicle for learning these skills, is an important but secondary goal of these two courses.

In the third course in the laboratory sequence (2953L), students will focus on learning physics by doing experimental physics experiments.

After completing this laboratory sequence, students will be ready to enter into experimental research in faculty laboratories.

A student who begins introductory physics in the Fall semester in 1912 will (most likely) not take a laboratory class in that semester. This student would take the lecture class 1912 and the laboratory class 1912L in the Spring semester.

A student who begins introductory physics in the Fall semester in either the 1501 or 1601 sequence may choose to take those lectures without the accompanying labs and then begin with PHYS 1912L in the spring semester, or they could choose to take both the 1501L/1601L and 1502L/1602L labs in parallel with their lecture courses. A student who takes either the 1501/2 or 1601/2 introductory lecture sequence at Vanderbilt and chooses to take both classes with the accompanying labs may complete the laboratory requirement by taking the four-credit laboratory sequence 1501L or 1601L, 1502L or 1602L, 2255L, 2953L rather than the three-semester laboratory sequence.

VII. Revised Rules for Honors in Physics and Honors in Astronomy Programs

Two related goals of the faculty are to encourage more students to pursue Honors in Physics or Honors in Astronomy and to allow more of these students to begin their Honors research programs before the Senior year and to defend their Honors theses no later than the end of the seventh semester (December) rather than at the end of the eighth semester (April). Students who successfully defend in the seventh semester will be able to include “Honors in Physics” or “Honors in Astronomy” on their applications to graduate and professional schools and for scholarships and jobs. They also are likely to receive stronger, more meaningful letters of recommendation from faculty research mentors if they engage in research earlier and longer, and more of them are likely to publish their research by defending their Honors projects in December and then continuing with their projects into the Spring semester of the senior year. As a result, we believe they will become stronger applicants in the competition for a wide variety of post-graduate opportunities.

Currently, students are admitted to Honors if they have attained a departmental GPA and overall GPA of at least 3.300. These minimum GPAs are College rules. We will not impose higher minimum GPAs for Honors.

New departmental rules for admission to the Honors program:

- Currently, students are admitted to Honors in the Department at the beginning of the Senior year (by precedent only; the timing for admission to Honors in Physics or Honors in Astronomy is not formally stated in the catalog). This precedent will be eliminated in favor of allowing (but not requiring) students to enter Honors as early as the beginning of the fifth semester (Junior year). This change is consistent with
Honors programs elsewhere in the College, some of which require entry in the fifth semester (e.g., Psychology) or the sixth semester (e.g., History, Chemistry).

- A student must have completed 2953L and either 2255 or 3651
- A student must meet the minimum GPA requirements of the College of Arts & Science.
- A student must submit a two-page research proposal describing the plans for their Honors project, which must be approved by the director of the departmental Honors program. Students interested in Honors will work with a faculty mentor to develop an appropriate research project that will be conducted under the guidance of that faculty member. The Honors project must have a substantial grounding in physics or astronomy, but may be conducted under the direct supervision of any faculty member in any department at Vanderbilt.

To graduate with Honors in Physics or Honors in Astronomy,

- A student must have both a departmental and overall GPA of at least 3.300 GPA.
- A student must earn a minimum of six credit hours in research classes. Credit hours earned in any research class (3850, 3851, 4998) will count toward the six-credit-hour requirement, but at least two of these credit hours must be earned in 4998. A student who earns credit for 3852 may satisfy this portion of the requirement with three credit hours of research earned at Vanderbilt, including at least two of these credit hours in 4998.
- A student must write a Senior Honors Thesis of high merit, as evaluated by the student’s Honors Examination Committee; this thesis may be submitted at any time during the Senior year.
- A student must demonstrate high attainment on an oral Honors Examination, in which they present and defend their work to the student’s Honors Examination Committee; this oral examination may take place at any time during the Senior year.
APPENDIX

A. The Existing Catalog Text Describing the Rules for the Physics Major

Program of Concentration in Physics

The departmental major provides a thorough grounding in the core areas of physics. It is suitable either as a preparation for careers in science and engineering or as a springboard for applying technical knowledge in such fields as business, medicine, law, public policy, and education. The major in the Department of Physics and Astronomy consists of 32 or 33 credit hours, depending on the student’s choice for requirement 1.

1. The second semester (Physics 1502 and 1502L or 1602 and 1602L or 1902) in introductory, calculus-based physics;
2. A 19-credit-hour core sequence, which consists of five courses covering the major subdisciplines of physics at an intermediate level and one semester each of the astronomy and physics seminars (Astronomy 2600, Physics 3600); and
3. 9 credit hours of electives in physics or astronomy, with at most 6 of these 9 credit hours earned from any combination of directed study (3840), independent study (3860), and/or Honors research (4998).

The core intermediate-level courses are: Concepts and Applications of Quantum Physics (Physics 2250 or 2250W); Modern Physics (Physics 2260 or 2260W); Thermal and Statistical Physics (Physics 3200 or 3207); Classical Mechanics I (Physics 2270); and Electricity, Magnetism, and Electrodynamics I (Physics 2290). Exceptionally well-qualified students should discuss their first-year program with the director of undergraduate studies for appropriate advising.

The electives required by the major may be satisfied by any combination of courses offered by the department that are at the 2000 level or above, with the exception of the seminar courses Physics 3600 and Astronomy 2600 (one credit hour of each is already required for the major). Other courses may count as an elective, such as courses offered by the engineering school (or other departments and schools) that are particularly relevant, such as a course in health physics, optics, or materials science.

Licensure for Teaching

Candidates for teacher licensure in physics at the secondary level may qualify by taking the basic physics major together with the requisite education courses described in the chapter on Licensure for Teaching in the Peabody College section of the catalog.

Honors Program

A student majoring in the Department of Physics and Astronomy may apply for admission to an honors program that allows the student to engage in independent study under the guidance of a faculty member, usually in an area related to an ongoing research program in the department. Admission to the Honors Program is granted only to students who have attained a departmental GPA and overall GPA of at least 3.300. The requirements for graduation with honors in physics or in astronomy are: at least a 3.3000 average both in the department and overall; at least 10 credit hours in Physics 3860, Physics 4990, Astronomy 3860, Astronomy 4998; a senior thesis of high merit; and high attainment on an oral honors examination given near the end of the senior year.

Departmental Minors

The physics or astronomy minor is suitable for students who wish to supplement a related discipline or simply have a general interest in the field. Note that research is not a requirement for either minor.

Minor in Physics

The minor requires a minimum of 19 credit hours of course work, distributed as follows:
Any first-semester calculus-based physics class with lab (1501 and 1501L, 1601 and 1601L, or 1901) 4-5
Any second-semester calculus-based physics class with lab (1502 and 1502L, 1602 and 1602L, 1902) 4-5
Physics 2250, 2250W, 2260, or 2260W 4
Two 2000-level or higher level physics courses, one of which may be a 3 Credit hour one semester directed study course (3840) or a 3 credit hour One semester independent study course (3860) 6
Physics 3600 1
Total credit hours: 19-21

Minor in Astronomy

Astronomy 1010 and 1010L; or 3000 and 1010L; or 1210 4
Four other astronomy courses, one of which may be a 3-credit-hour directed Study (ASTR 3840) 12
Two semester of ASTR 2600 2
Total credit hours: 18
B. Proposed New Catalog Text Describing the Rules for the New Physics major and minor and Astronomy minor

Program of Concentration in Physics

The departmental major provides a thorough grounding in the core areas of physics. It is suitable either as preparation for careers in science and engineering or as a springboard for applying technical knowledge in such fields as business, medicine, law, public policy, and education. The major in the Department of Physics and Astronomy consists of 31-32 credit hours of course work.

1. An 12-credit-hour core sequence, which consists of four courses (chosen by the student from a list of five) covering the major subdisciplines of physics;
2. A 3-credit-hour, three-semester sequence of laboratory work;
3. 9 credit hours of pedagogical course work electives in physics and/or astronomy, not including research;
4. A 7-credit-hour Capstone program, including Computational Physics, research, and a seminar on presenting physics research.

The five core courses are: and Modern Physics and the Quantum World (2255); Classical Mechanics (2275); Electricity, Magnetism, and Electrodynamics I (2290); Statistical Physics (3200); Quantum Mechanics I (3651).

The core laboratories are Laboratory Principles I (1912L), Laboratory Principles II (2255L) and Introduction to Experimental Research (2953L). Students who enter the major by taking 1501 or 1501L, 1502 or 1502L at Vanderbilt may satisfy the core laboratory requirement by completing a four-credit laboratory sequence: 1501L or 1601L, 1502L or 1602L, 2255L and 2953L. Students considering majoring in physics who begin in 1501 or 1501L in the Fall semester are encouraged to take the combination 1502 + 1912L or 1602 + 1912L in the Spring semester. Students may not use AP credit for 1601L and 1602L to satisfy any portion of the laboratory sequence requirements. Any student considering majoring in physics is strongly encouraged to consult with the Director of Undergraduate Studies before registering for classes.

The course electives (9 credit hours) may be taken from any 2000-level or higher PHYS or ASTR courses. Other courses may count as electives, such as courses offered by the engineering school (or other departments and schools) that are particularly relevant, such as a course in environmental studies, health physics, optics, or materials science. Such exceptions must be approved by the Director of Undergraduate Studies. All elective credit hours must be from pedagogical course work; research hours (3850, 3851, 4998) do not count toward this requirement.

The Capstone Program consists of Computational Physics (3790), three credit hours of research (3850, 3851 or 4998), taken across one or more semesters, and the Seminar in Presenting Physics Research (3600). Physics-related research done in other departments and programs, supervised by Vanderbilt faculty, which must be pre-approved by the Director of Undergraduate Studies, is also permitted in satisfaction of the research requirement.

An enhanced version of the Capstone Program, in which a student earns credit for 3851, 3852 or 4998 (but not 3850) and then completes an additional semester of 3600, will enable a student majoring in Physics to complete their Immersion Experience within the disciplines of either Physics or Astronomy.

Computer Science course work: All 2000-level and higher PHYS courses assume students have working skills in programming. These skills may be learned outside of a regular course, but should be equivalent to that taught in CS 1101: Programming and Problem Solving (3). Students who do not already have these skills are strongly advised to take this class in the first semester, prior to beginning the three-semester laboratory sequence in the second semester. In addition, the following Computer Science and/or Scientific Computing courses are strongly recommended for all physics majors: Program Design and Data Structures (CS 2201) or Program Design and Data Structures for Scientific Computing (CS 2204); Algorithms (CS 3250) or Scientific Computing Toolbox (SC 3250); and High Performance Computing (SC 3260). Physics majors pursuing a second major or minor in Computer Science should take CS 2201; physics majors pursuing a minor in Scientific Computing should take CS 2204.

Mathematics course work: All physics majors are expected to have high-level skills in mathematics in order to be successful in PHYS classes and to prepare for graduate work. MATH courses are not formally required for the major.
in physics; however, most physics courses identify MATH prerequisite or co-requisite courses in order to indicate the mathematical skill-level assumed for that class. Multivariable calculus is a co-requisite for 2255 and a prerequisite for all other 2000-level or higher PHYS courses. Physics majors are expected to develop a working knowledge of single-variable calculus, multivariable calculus and ordinary differential equations. The following courses are those strongly recommended for physics majors:

1. Accelerated Calculus I (1300; 4) and Accelerated Calculus II (1301; 4);
2. Multivariable Calculus (2300; 3) or Multivariable Calculus and Linear Algebra (2500; 4 and 2501; 4); and
3. Methods of Ordinary Differential Equations (2420; 3) or Ordinary Differential Equations (2610; 3)

In addition, for Physics majors considering post-graduate work in Physics or a related field, the following PHYS and MATH courses are strongly recommended as electives:

- PHYS 2291 (Electricity, Magnetism, and Electrodynamics II), 3652 (Quantum Mechanics II), 4005 (Mathematical Methods of Physics);
- MATH 2410 (Methods of Linear Algebra) or 2600 (Linear Algebra); 2820 Introduction to Probability and Mathematical Statistics; 2820L Statistics Laboratory; 3110 Complex Variables; 3120 Introduction to Partial Differential Equations; 3130 Fourier Analysis; and 3600 Advanced Engineering Mathematics.

Licenses for Teaching
Candidates for teacher licensure in physics at the secondary level may qualify by taking the basic physics major together with the requisite education courses described in the chapter on Licensure for Teaching in the Peabody College section of the catalog.

Honors Program
A student majoring in the Department of Physics and Astronomy may apply for admission to the honors program (Honors in Physics or Honors in Astronomy) that allows the student to engage in advanced research under the guidance of a faculty member, usually in an area related to an ongoing research program in the department.

Students interested in Honors will work with a faculty mentor to develop an appropriate research project that will be conducted under the guidance of that faculty member. The Honors project must have a substantial grounding in physics or astronomy, but may be conducted under the direct supervision of any faculty member in any department at Vanderbilt.

To be admitted to the Honors program, a student must have completed 2953L, either 2255 or 3651, and meet the minimum GPA requirements of the College of Arts & Science. In addition, a student must submit a two-page research proposal describing the plans for their Honors project, which must be approved by the director of the departmental Honors program.

To graduate with Honors, a student must
- Have at least a 3.300 GPA in both the department and overall.
- Earn a minimum of six credit hours in research classes (3950, 3951, 4998), with at least two of these credit hours earned in 4998. A student who earns credit for 3852 may satisfy this portion of the requirement with three credit hours of research earned at Vanderbilt, including at least two of these credit hours in 4998.
- Write a senior thesis of high merit, as evaluated by the student’s Honors Examination Committee; this thesis may be submitted at any time during the senior year.
- Demonstrate high attainment on an oral honors examination in which they present and defend their work to the student’s Honors Examination Committee; this oral examination may take place at any time during the senior year.

Departmental Minors
The physics or astronomy minor is suitable for students who wish to supplement a related discipline or simply have a general interest in the field. Note that research is not a requirement for either minor.

Minor in Physics
The minor requires a minimum of 19 credit hours of course work, distributed as follows:

- Any first-semester physics class (1501, 1601, 1911, 2051) 3-4
- Any first-semester physics laboratory (1501L, 1601L, 1912L, 2052) 1
- Any second-semester physics class (1502, 1602, 1912, 2053) 3-4
- Any second-semester physics laboratory (1502L, 1602L, 2255L, 2054) 1
- Physics 2255 or 3651 3
- Six credit hours of electives. These may be selected from any 2000-level or higher-level PHYS courses or from three-credit-hour non-PHYS courses, the latter if approved by the Director of Undergraduate Studies, and may include up to three credit hours of research (3850, 3851, 4998).

Total credit hours: 17-19

Minor in Astronomy

The minor requires 16 credit hours of course work, distributed as follows:

- Astronomy 1010 and either 1010L or 1020L; or 1210 4
- Astronomy 2110 3
- Astronomy 3000 3
- Two other astronomy courses, one of which may be a three-credit-hour one semester research project (3850, 3851, 4998). (Note that only Physics majors pursuing Honors in Astronomy are eligible to enroll in 4998.) 6

Total credit hours: 16
C. Redlined version of Catalog Text, Incorporating Revised Catalog Text

Program of Concentration in Physics

The departmental major provides a thorough grounding in the core areas of physics. It is suitable either as a preparation for careers in science and engineering or as a springboard for applying technical knowledge in such fields as business, medicine, law, public policy, and education. The major in the Department of Physics and Astronomy consists of 32 or 33 credit hours, depending on the student’s choice for requirement 1.

1. The second semester (Physics 1502 and 1502L or 1602 and 1602L or 1902) in introductory, calculus-based physics;
2. A 19-credit-hour core sequence, which consists of five courses covering the major subdisciplines of physics at an intermediate level and one semester each of the astronomy and physics seminars (Astronomy 2600, Physics 3600); and
3. 9 credit hours of electives in physics or astronomy, with at most 6 of these 9 credit hours earned from any combination of directed study (3840), independent study (3860), and/or Honors research (1900).

1. An 12-credit-hour core sequence, which consists of four courses (chosen by the student from a list of five) covering the major subdisciplines of physics;
2. A 3-credit-hour, three-semester sequence of laboratory work;
3. 9 credit hours of pedagogical course work electives in physics and/or astronomy, not including research;
4. A 7-credit-hour Capstone program, including Computational Physics, research, and a seminar on presenting physics research.

The five core courses are: Modern Physics and the Quantum World (2255); Classical Mechanics (2275); Electricity, Magnetism, and Electrodynamics I (2290); Statistical Physics (3200); Quantum Mechanics I (3651).

The core intermediate-level courses are: Concepts and Applications of Quantum Physics (Physics 2250 or 2250W); Modern Physics (Physics 2260 or 2260W); Thermal and Statistical Physics (Physics 3200 or 3207); Classical Mechanics I (Physics 2270); and Electricity, Magnetism, and Electrodynamics I (Physics 2290). Exceptionally well-qualified students should discuss their first-year program with the director of undergraduate studies for appropriate advising.

The electives required by the major may be satisfied by any combination of courses offered by the department that are at the 2000 level or above, with the exception of the seminar courses Physics 3600 and Astronomy 2600 (one credit hour of each is already required for the major). Other courses may count as an elective, such as courses offered by the engineering school (or other departments and schools) that are particularly relevant, such as a course in health physics, optics, or materials science.

The core laboratories are Laboratory Principles I (1912L), Laboratory Principles II (2255L) and Introduction to Experimental Research (2953L). Students who enter the major by taking 1501 or 1501L, 1501L or 1601L, 1502 or 1602, and 1502L or 1602L at Vanderbilt may satisfy the core laboratory requirement by completing a four-credit laboratory sequence: 1501L or 1501L, 1502L or 1602L, 2255L and 2953L. Students considering majoring in physics who begin in 1501 or 1501L and 1501L or 1601L in the Fall semester are encouraged to take the combination 1502 + 1912L or 1602 + 1912L in the Spring semester. Students may not use AP credit for 1601L and 1602L to satisfy any portion of the laboratory sequence requirements. Any student considering majoring in physics is strongly encouraged to consult with the Director of Undergraduate Studies before registering for classes.

The course electives (9 credit hours) may be taken from any 2000-level or higher PHYS or ASTR courses. Other courses may count as electives, such as courses offered by the engineering school (or other departments and schools) that are particularly relevant, such as a course in environmental studies, health physics, optics, or materials science. Such exceptions must be approved by the Director of Undergraduate Studies. All elective credit hours must be from
pedagogical course work; research hours (3850, 3851, 4998) do not count toward this requirement.

The Capstone Program consists of Computational Physics (3790), three credit hours of research (3850, 3851 or 4998), taken across one or more semesters, and the Seminar in Presenting Physics Research (3600). Physics-related research done in other departments and programs, supervised by Vanderbilt faculty, which must be pre-approved by the Director of Undergraduate Studies, is also permitted in satisfaction of the research requirement.

An enhanced version of the Capstone Program, in which a student earns credit for 3851, 3852 or 4998 (but not 3850) and then completes an additional semester of 3600, will enable a student majoring in Physics to complete their Immersion Experience within the disciplines of either Physics or Astronomy.

Computer Science course work: All 2000-level and higher PHYS courses assume students have working skills in programming. These skills may be learned outside of a regular course, but should be equivalent to that taught in CS 1101: Programming and Problem Solving (3). Students who do not already have these skills are strongly advised to take this class in the first semester, prior to beginning the three-semester laboratory sequence in the second semester. In addition, the following Computer Science and/or Scientific Computing courses are strongly recommended for all physics majors: Program Design and Data Structures (CS 2201) or Program Design and Data Structures for Scientific Computing (CS 2204); Algorithms (CS 3250) or Scientific Computing Toolbox (SC 3250); and High Performance Computing (SC 3260). Physics majors pursuing a second major or minor in Computer Science should take CS 2201; physics majors pursuing a minor in Scientific Computing should take CS 2204.

Mathematics course work: All physics majors are expected to have high-level skills in mathematics in order to be successful in PHYS classes and to prepare for graduate work. MATH courses are not formally required for the major in physics; however, most physics courses identify MATH prerequisite or co-requisite courses in order to indicate the mathematical skill-level assumed for that class. Multivariable calculus is a co-requisite for 2255 and a prerequisite for all other 2000-level or higher PHYS courses. Physics majors are expected to develop a working knowledge of single-variable calculus, multivariable calculus, and ordinary differential equations. The following courses are those strongly recommended for physics majors:

1. Accelerated Calculus I (1300; 4) and Accelerated Calculus II (1301; 4);
2. Multivariable Calculus (2300; 3) or Multivariable Calculus and Linear Algebra (2500; 4 and 2501; 4); and
3. Methods of Ordinary Differential Equations (2420; 3) or Ordinary Differential Equations (2610; 3)

In addition, for Physics majors considering post-graduate work in Physics or a related field, the following PHYS and MATH courses are strongly recommended as electives:

- PHYS 2291 (Electricity, Magnetism, and Electrodynamics II), 3652 (Quantum Mechanics II), 4005 (Mathematical Methods of Physics);
- MATH 2410 (Methods of Linear Algebra) or 2600 (Linear Algebra); 2820 Introduction to Probability and Mathematical Statistics; 2820L Statistics Laboratory; 3110 Complex Variables; 3120 Introduction to Partial Differential Equations; 3130 Fourier Analysis; and 3600 Advanced Engineering Mathematics.

Licensure for Teaching
Candidates for teacher licensure in physics at the secondary level may qualify by taking the basic physics major together with the requisite education courses described in the chapter on Licensure for Teaching in the Peabody College section of the catalog.

Honors Program
A student majoring in the Department of Physics and Astronomy may apply for admission to an honors program that allows the student to engage in independent study under the guidance of a faculty member, usually in an area related to an ongoing research program in the department. Admission to the Honors Program is granted only to students who have attained a departmental GPA and overall GPA of at least 3.300. The requirements for graduation with honors in physics or in astronomy are: at least a 3.300 average both in the department and overall; at least 10 credit
hours in Physics 3860, Physics 4990, Astronomy 3860, Astronomy 4998; a senior thesis of high merit; and high attainment on an oral honors examination given near the end of the senior year.

A student majoring in the Department of Physics and Astronomy may apply for admission to the honors program (Honors in Physics or Honors in Astronomy) that allows the student to engage in advanced research under the guidance of a faculty member, usually in an area related to an ongoing research program in the department.

Students interested in Honors will work with a faculty mentor to develop an appropriate research project that will be conducted under the guidance of that faculty member. The Honors project must have a substantial grounding in physics or astronomy, but may be conducted under the direct supervision of any faculty member in any department at Vanderbilt.

To be admitted to the Honors program, a student must have completed 2953L, either 2255 or 3651, and meet the minimum GPA requirements of the College of Arts & Science. In addition, a student must submit a two-page research proposal describing the plans for their Honors project, which must be approved by the director of the departmental Honors program.

To graduate with Honors, a student must

- Have at least a 3.300 GPA in both the department and overall.
- Earn a minimum of six credit hours in research classes (3950, 3951, 4998), with at least two of these credit hours earned in 4998. A student who earns credit for 3852 may satisfy this portion of the requirement with three credit hours of research earned at Vanderbilt, including at least two of these credit hours in 4998.
- Write a senior thesis of high merit, as evaluated by the student’s Honors Examination Committee; this thesis may be submitted at any time during the senior year.
- Demonstrate high attainment on an oral honors examination in which they present and defend their work to the student’s Honors Examination Committee; this oral examination may take place at any time during the senior year.

**Departmental Minors**

The physics or astronomy minor is suitable for students who wish to supplement a related discipline or simply have a general interest in the field. Note that research is not a requirement for either minor.

**Minor in Physics**

The minor requires a minimum of 19 credit hours of course work, distributed as follows:

<table>
<thead>
<tr>
<th>Course Description</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any first-semester calculus-based physics class with lab (1501 and 1501L, 1601 and 1601L, or 1901)</td>
<td>4-5</td>
</tr>
<tr>
<td>Any second-semester calculus-based physics class with lab (1502 and 1502L, 1602 and 1602L, 1902)</td>
<td>4-5</td>
</tr>
<tr>
<td>Physics 2250, 2250W, 2260, or 2260W</td>
<td>4</td>
</tr>
<tr>
<td>Two 2000-level or higher level physics courses, one of which may be a 3 Credit hour one semester directed study course (3840) or a 3 credit hour one semester independent study course (3860)</td>
<td>6</td>
</tr>
<tr>
<td>Physics 3600</td>
<td>1</td>
</tr>
</tbody>
</table>

Total credit hours: 19-21

The minor requires a minimum of 17 credit hours of course work, distributed as follows:

<table>
<thead>
<tr>
<th>Course Description</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any first-semester physics class (1501, 1601, 1911, 2051)</td>
<td>3-4</td>
</tr>
<tr>
<td>Any first-semester physics laboratory (1501L, 1601L, 1912L, 2052)</td>
<td>1</td>
</tr>
<tr>
<td>Any second-semester physics class (1502, 1602, 1912, 2053)</td>
<td>3-4</td>
</tr>
<tr>
<td>Any second-semester physics laboratory (1502L, 1602L, 2255L, 2054)</td>
<td>1</td>
</tr>
</tbody>
</table>
Physics 2255 or 3651  
Six credit hours of electives. These may be selected from any 2000-level or  
higher-level PHYS courses or from three-credit-hour non-PHYS courses, the  
latter if approved by the Director of Undergraduate Studies, and may  
include up to three credit hours of research (3850, 3851, 4998).  

Total credit hours: 17-19

Minor in Astronomy

Astronomy 1010 and 1010L, or 3000 and 1010L, or 1210 4  
Four other astronomy courses, one of which may be a 3-credit-hour directed  
Study (ASTR 3840) 12  
Two semester of ASTR 2600 2  

Total credit hours: 18  

The minor requires 16 credit hours of course work, distributed as follows:

Astronomy 1010 and either 1010L or 1020L; or 1210 4  
Astronomy 2110 3  
Astronomy 3000 3  
Two other astronomy courses, one of which may be a three-credit-hour  
one semester research project (3850, 3851, 4998). (Note that only Physics  
majors pursuing Honors in Astronomy are eligible to enroll in 4998.) 6  

Total credit hours: 16
D. Sample 4-yr program: students with no AP credit in MATH or PHYS and no calculus background

First semester: (13)
- PHYS 1501 or 1601 (3) [optional: plus 1501L or 1601L (1)]
- MATH 1300 (4)
- CS 1101 (3)
- AXLE: first-year writing seminar and Humanities and Creative Arts #1 (3)

Second semester: (11)
- PHYS 1502 or 1602 (3)
- PHYS 1912L (1) (preferred) or 1502L or 1602L (1)
- MATH 1301 (4)
- AXLE: Humanities and Creative Arts #2 and 1000-level W (3)

Third semester (13-14)
- PHYS 2255 (3)
- PHYS 2255L (1)
- MATH 2300 (3) or 2500 (4)
- AXLE: social and behavioral science #1 (3)
- AXLE: Humanities and Creative Arts #3 and 1000-level W (3)

Fourth semester: (13)
- PHYS 2275 (3)
- MATH 2420 or MATH 2610 (3)
- PHYS 2953L (1)
- AXLE: social and behavioral science #2 (3)
- AXLE: perspectives (3)

Fifth semester: (15-16)
- PHYS 2290 (3)
- PHYS 3600 (1)
- PHYS course elective #1 (3)
- MATH 2410 (3) or 2600 (3) or 2501 (4)
- AXLE: foreign language first semester (5)

Sixth semester: (17)
- PHYS 3200 (3)
- PHYS course elective #2 (3)
- PHYS Research: 3850, 3851, or 4998 (3)
- AXLE: foreign language second semester and International Cultures #1 (5)
- AXLE: US History (3)

Seventh semester: (12)
- PHYS 3790 (3)
- optional research (PHYS 3850, 3851, 4998) (3)
- PHYS course elective #3 (3)
- AXLE: International Cultures #2 (3)

Eighth semester: (9)
- optional research (3850, 3851, 4998) (3)
- optional PHYS electives (3)
- AXLE: Int’l Cultures #3 (3)
E. Sample 4-yr program: students entering with no AP credit in MATH or PHYS but with enough calculus background to start in 1911

First semester:
- PHYS 1911
- MATH 1300
- CS 1101

Second semester:
- PHYS 1912
- PHYS 1912L
- MATH 1301

Third semester
- PHYS 2255
- PHYS 2255L
- MATH 2300 or 2500

Fourth semester:
- PHYS 2275
- PHYS 2953L
- MATH 2420 or MATH 2610

Fifth semester:
- PHYS 2290
- PHYS 3600
- PHYS course elective #1
- MATH 2410 (3) or 2600 (3) or 2501

Sixth semester:
- PHYS 3200
- PHYS course elective #2
- Research (3850, 3851, or 4998)

Seventh semester:
- PHYS 3790
- optional research (3850, 3851, 4998)
- PHYS course elective #3

Eighth semester:
- optional research (3850, 3851, 4998)
- optional PHYS electives
F. Sample 4-yr program: students entering with AP credit for MATH 1300 and 1301 and who begin taking PHYS in their first semester

First semester:
- PHYS 1911
- MATH 2300 or MATH 2500
- CS 1101

Second semester:
- PHYS 1912
- PHYS 1912L
- MATH 2410 or MATH 2600; or MATH 2501

Third semester:
- PHYS 2255
- PHYS 2255L
- MATH 2420 or MATH 2610

Fourth semester:
- PHYS 2275
- PHYS 2953L

Fifth semester:
- PHYS 2290
- PHYS 3600
- PHYS course elective #1

Sixth semester:
- PHYS 3200
- PHYS course elective #2
- Research (3850, 3851, 4998)

Seventh semester:
- PHYS 3790
- optional research (3850, 3851, 4998)
- PHYS course elective #3

Eighth semester:
- optional research (3850, 3851, 4998)
- optional PHYS electives
G. Sample 4-yr program: for students entering with AP credit for MATH 1300/1301 and PHYS 1601/1602

First semester:
- PHYS 2255
- MATH 2300 or MATH 2500
- CS 1101

Second semester:
- PHYS 2275
- PHYS 1912L
- MATH 2410 or MATH 2600; or MATH 2501

Third semester:
- PHYS 2290
- PHYS 2255L
- PHYS course elective #1
- MATH 2420 or MATH 2610

Fourth semester:
- PHYS 3200
- PHYS 2953L
- PHYS course elective #2
- research (3850, 3851)

Fifth semester:
- PHYS 3600
- PHYS 3790
- optional research (3850, 3851, 4998)
- PHYS course elective #3

Sixth semester:
- optional research (3850, 3851, 4998)
- optional course electives

Seventh semester:
- optional research (3850, 3851, 4998)
- optional course electives

Eighth semester:
- optional research (3850, 3851, 4998)
- optional course electives
H. Revision of Course Description of Physics Seminar

Existing course description:

**PHYS 3600. Physics Seminar.** [Formerly PHYS 250] Directed readings and discussions of current topics in physics. Preference to majors for enrollment. Prerequisite or corequisite: 2250, 2250W, 2260, or 2260W. [1] (No AXLE credit)

Revised course description:

**PHYS 3600. Seminar in Presenting Physics Research.** Introduction, instruction and practice in skills for presenting scientific research results. Prerequisite: major or minor in Physics; 2255 or 3651. May be repeated for credit more than once, but students may earn only 1 credit per semester of enrollment and may count only 1 credit toward the major or minor in physics. [1] (No AXLE credit)

The revised physics seminar will build student skills in communicating research and engaging with the larger scientific community. The seminar will be co-scheduled with the department colloquia.

- Students will receive instruction on how to give a well-structured presentation.
- Students will receive guidance for how to read a scientific paper and write an abstract for a paper/meeting. Papers should be suggested by the colloquium speaker.
- Students will be asked to attend selected colloquia and meet with the colloquium speaker. Subsequent seminars could discuss the positive and negative aspects of the colloquium presentations.
- Students taking the course as part of their Immersion in Physics Experience will be required to make a 10 minute American Physics Society (APS) style talk on their project.
I. Revision of Course Descriptions of Research Classes

Existing course descriptions for courses to be deleted:

PHYS 3840. Directed Study. Individual research or readings under close faculty supervision. May be repeated for a total of 10 credits, but students may earn only up to 5 credits per semester of enrollment. Prerequisite: either 2250 or 2250W and either 2260 or 2260W. [1-5] (No AXLE credit)

PHYS 3860. Independent Study. Introduction to independent research and scholarly investigation under faculty supervision. May be repeated for a total of 10 credits, but students may earn only up to 6 credits per semester of enrollment. Prerequisite or corequisite: multivariable calculus and either 2250 or 2250W and either 2260 or 2260W. [1-6; maximum of 10 credits total for all semesters of PHYS 3860] (No AXLE credit)

ASTR 3840. Directed Studies. Individual research or readings under close faculty supervision. May be repeated for a total of 10 credits, but students may earn only up to 5 credits per semester of enrollment. [1-5; maximum of 10 credits total for all semesters of ASTR 3840] (No AXLE credit)

ASTR 3860. Independent Study. Introduction to independent research and scholarly investigation under faculty supervision. May be repeated for a total of 10 credits, but students may earn only up to 6 credits per semester of enrollment. [1-6; maximum of 10 credits total for all semesters of ASTR 3860] (No AXLE credit)

New course descriptions:

These new courses include two courses (PHYS 3852, ASTR 3852) modeled on the Ingram Scholars (UNIV 106) and Syburre (UNIV 108) classes, both of which are zero credit hour courses but enable students to include these activities on their transcripts.

PHYS 3850. Undergraduate Research. Research and scholarly investigation or directed readings in physics under close supervision of sponsoring faculty member. Enrollment by arrangement with sponsoring faculty member and approval of Director of Undergraduate Studies. May be repeated for credit, for a total of no more than 10 total credit hours and for no more than 5 credit hours per semester. [1-5] (No AXLE credit)

PHYS 3851. Undergraduate Immersion Research. Research and scholarly investigation or directed readings in physics under close supervision of sponsoring faculty member, including end-of-semester oral presentation or written report. Enrollment by arrangement with sponsoring faculty member and approval of Director of Undergraduate Studies. May be repeated for credit, for a total of no more than 10 total credit hours and for no more than 5 credit hours per semester. [1-5] (No AXLE credit)

PHYS 3852. Undergraduate Summer or Off-Campus Immersion Research. Research and scholarly investigation in physics conducted in the summer at either Vanderbilt or in an approved off campus program, including an end-of-session oral presentation or written report. Must be fulltime effort for a minimum of six weeks. Enrollment by approval of Director of Undergraduate Studies. Not for credit. [0] (No AXLE credit)

ASTR 3850. Undergraduate Research. Research and scholarly investigation or directed readings in astronomy under close supervision of sponsoring faculty member. Enrollment by arrangement with sponsoring faculty member and approval of Director of Undergraduate Studies. May be repeated for credit, for a total of no more than 10 total credit hours and for no more than 5 credit hours per semester. [1-5] (No AXLE credit)

ASTR 3851. Undergraduate Immersion Research. Research and scholarly investigation or directed readings in astronomy under close supervision of sponsoring faculty member, including end-of-semester oral presentation or written report. Enrollment by arrangement with sponsoring faculty member and
approval of Director of Undergraduate Studies. May be repeated for credit, for a total of no more than 10
total credit hours and for no more than 5 credit hours per semester. [1-5] (No AXLE credit)

**ASTR 3852. Undergraduate Summer or Off-Campus Immersion Research.** Research and scholarly
investigation in astronomy conducted in the summer at either Vanderbilt or in an approved off campus
program, including an end-of-session oral presentation or written report. Must be fulltime effort for a
minimum of six weeks. Enrollment by approval of Director of Undergraduate Studies. Not for credit. [0]
(No AXLE credit)
J. Revision of Course Descriptions for Honors Classes

Existing course descriptions:

**PHYS 4998. Honors Research and Senior Thesis.** Independent experimental or theoretical investigations of basic problems in physics under faculty supervision, culminating in a written thesis submitted to the faculty. Required for departmental honors in physics. May be repeated for a total of 10 credits, but students may earn only up to 6 credits per semester of enrollment. Prerequisite: senior standing, major in Physics and Astronomy, and departmental approval. Prerequisite or corequisite: multivariable calculus and either 225 or 2250W and either 226 or 2260W. [1-6; maximum of 10 credits total for all semester of PHYS 4998] (No AXLE credit)

**ASTR 4998. Honors Research and Senior Thesis.** Independent experimental or theoretical investigations of basic problems in astronomy under faculty supervision which culminate in a written thesis submitted to the faculty. Required for departmental honors. Open to senior majors with departmental approval. May be repeated for a total of 10 credits, but students may earn only up to 6 credits per semester of enrollment. [1-6; maximum of 10 credits total for all semester of PHYS 4998] (No AXLE credit)

Revised course descriptions:

**PHYS 4998. Honors Research and Senior Thesis.** Independent experimental or theoretical investigations of basic problems in physics under faculty supervision, culminating in a written thesis submitted to and an oral defense presented to a departmental faculty examination committee. Required for departmental honors in Physics. May be repeated for a total of 10 credits, but students may earn only up to 6 credits per semester of enrollment. Prerequisite: major in Physics, Junior or Senior standing, and departmental approval. [1-6] (No AXLE credit)

**ASTR 4998. Honors Research and Senior Thesis.** Independent experimental or theoretical investigations of basic problems in astronomy and astrophysics under faculty supervision, culminating in a written thesis submitted to and an oral defense presented to a departmental faculty examination committee. Required for departmental honors in Astronomy. May be repeated for a total of 10 credits, but students may earn only up to 6 credits per semester of enrollment. Prerequisite: major in Physics, Junior or Senior standing, and departmental approval. [1-6] (No AXLE credit)
K. Revision of Course Description for *Computational Physics*

Existing course description of course to be deleted:

**PHYS 2237. Computational Physics.** Topics in modern physics analyzed exclusively with computer programs. Three-body solar system orbits. Random walk diffusion and entropy growth. Magnetism in the second order using model, non-equilibrium molecular dynamics. Solutions to the Schrödinger equation with numerical methods. Prerequisite: either 1502 or 1602 or 1902; and either MATH 1201 or 1301. [3] (MNS)

New course description:


Note that the changed course number is intended to reflect the significantly higher-level of this re-designed course.
L. **New Undergraduate Course in Mathematical Methods of Physics**

Rather than create an undergraduate course in Mathematical Methods of Physics, and rather than require such a course for all Physics majors, the UPC recommends creating an undergraduate course to be paired with PHYS 8005. A few undergraduates with strong backgrounds who aspire to pursue graduate work in physics would be encouraged to take this “new” course.

The prerequisites (in PHYS, Classical Mechanics and Electricity & Magnetism I; in MATH, ordinary differential equations) ensure that only well-prepared physics majors enroll in this course.

**PHYS 4005. Mathematical Methods for Physicists.** Linear spaces and operators; matrix algebra; differential equations; Green's function; and complex analysis. May include variational calculus; perturbation methods; group theory. Prerequisite: 2275, 2290; MATH 2400, 2420 or 2610. [3] (MNS)
M. Revisions of Course Descriptions for Astronomy Courses and the Rules for the Astronomy Minor

The lower-level astronomy courses and the astronomy program have evolved significantly over the last decade. By eliminating ASTR 2600, we are forced to rewrite the rules for the Astronomy minor and we have the opportunity to examine the courses we teach.

We propose two significant changes to courses that will also impact the rules for the minor:

a. Current rules preclude a student from taking 1010 after 3000 but allow a student to take 1010 and then 3000; however, ASTR 3000 (Principles of Astrophysics) has evolved sufficiently far from ASTR 1010 (Introductory Astronomy: Stars and Galaxies) that students should now be allowed to take both courses.

b. ASTR 3000 and ASTR 2110 (The Solar System) have both evolved, due to the rapid growth in knowledge and importance of exoplanets, such that they overlap. We wish to eliminate this overlap and make the instruction about exoplanets in these two courses complementary.

Existing course descriptions of courses to be revised:

ASTR 1010. Introductory Astronomy: Stars and Galaxies. Observed and physical properties of stars. Supernovae, neutron stars, and black holes. Our Milky Way galaxy and other galaxies. Cosmology, dark matter, dark energy, and the Big Bang. No credit for students who have earned credit for 1210 or 3000. [3] (MNS)

Note: only change is in “no credit” rule.

ASTR 2110. The Solar System. The sky, ancient astronomy, orbits and gravity; seasons, the calendar, phases and motions of the moon; tides, eclipses, light and telescopes, the terrestrial planets, the giant planets and their moons and rings, asteroids, comets, meteorites, extra-solar planets, formation of planetary systems, the sun. [3] (MNS)

ASTR 3000. Principles of Astrophysics. Origin and evolution of matter. The tools and methods of astrophysics, including light and telescopes. Cosmology and the Big Bang. Galaxies and star formation; physics of stars, including nucleosynthesis and stellar death; the solar system and the search for other worlds. Prerequisite: either PHYS 1501, 1601 or 1901 and either MATH 1200 or 1300. [3] (MNS)

ASTR 3600. Stellar Astrophysics. Physics of stellar structure and evolution, including nuclear energy generation, equations of state, and heat transfer by radiation and convection. Numerical stellar models. Observational aspects of stellar astrophysics. Prerequisite: either MATH 2400, 2420, or 2610; either PHYS 3200 or 3207; and either PHYS 2250 or 2250W. [3] (MNS)

ASTR 3700. Galactic Astrophysics. Interstellar matter and gaseous nebulae, the structure and evolution of normal galaxies, active galactic nuclei and quasars, and observational cosmology. No credit for students who have earned credit for 8040. Prerequisite: MATH 2400, 2420, or 2610 and either PHYS 2250 or 2250W. [3] (MNS)

Revised course descriptions:


Note: only change is in “no credit” rule.

ASTR 2110. The Solar System and Life in the Universe. The sky, ancient astronomy, orbits and gravity. Seasons, the calendar, phases and motions of the moon, tides, eclipses. Terrestrial planets, giant planets and their moons and rings, asteroids, comets, meteorites, the Sun. Habitable zones for planets and moons, extremophiles and the possibility of life on other worlds. [3] (MNS)
**ASTR 3000. Principles of Astrophysics.** The tools and methods of astrophysics, including light and telescopes. Cosmology, the Big Bang, and the origin and evolution of matter. Galaxies and star formation; physics of stars, including nucleosynthesis and stellar death. Techniques for discovery and measuring properties of exoplanets. Prerequisite: either PHYS 1501, 1601 or 1901 and either MATH 1200 or 1300. [3] (MNS)

**ASTR 3600. Stellar Astrophysics.** Physics of stellar structure and evolution, including nuclear energy generation, equations of state, and heat transfer by radiation and convection. Numerical stellar models. Observational aspects of stellar astrophysics. Prerequisite: either MATH 2400, 2420, or 2610; either 2255 or 3651; 3200; and one of CS 1101 or 1103. [3] (MNS)

Note: changes only in prerequisites.

**ASTR 3700. Galactic Astrophysics.** Interstellar matter and gaseous nebulae, the structure and evolution of normal galaxies, active galactic nuclei and quasars, and observational cosmology. No credit for students who have earned credit for 8040. Prerequisite: MATH 2400, 2420, or 2610; either 2255 or 3651. Corequisite: one of CS 1101 or 1103. [3] (MNS)

Note: changes only in prerequisites.

Revised rules for the Minor in Astronomy

*Minor in Astronomy*

Astronomy 1010 and either 1010L or 1020L; or 1210 4
Astronomy 2110 3
Astronomy 3000 3
Two other astronomy courses, one of which may be a 3 credit hour one semester research project (3850, 3851, 4998). (Note that only Physics majors pursuing Honors in Astronomy are eligible to enroll in 4998.) 6

Total credit hours: 16
Laboratory Skills and Pedagogy for First Two Semesters of Laboratory Classes and Course Descriptions for PHYS 1912L and 2255L

The revised, stand-alone first-semester (PHYS 1912L) and second-semester (PHYS 2255L) laboratory classes are designed to teach students fundamental laboratory skills. Learning physics, which will happen because they will do physics experiments as a vehicle for learning these skills, is almost incidental to the goals of these two classes. Upon completion of these two classes, students will be prepared to focus on learning physics by doing physics experiments and will be ready to enter into experimental research in faculty laboratories.

1. Experimentation
   A. Scientific Method
      i. Observe, Describe, and Quantify;
      ii. Hypothesis/Null Hypothesis;
      iii. Test Experiment;
      iv. Data Analysis;
      v. Evidence-based Explanation;
      vi. Presenting Findings;
      vii. Alternative approaches.
   b. Starting Points
      i. From Theoretical Concepts - Experiment to see if data is consistent with theory.
      ii. From Experimental Data - Use analysis of data to develop theories.
   c. Theoretical Work of An Experiment
      i. Free-body diagrams of experimental set up
      ii. Determining Theoretical Equations of the set up that makes experimental predictions.
      iii. Verbal Explanation of theoretical concepts and the experimental objectives.
   d. Experimental Design
      ii. Define experimental objective and questions to be answered
      iii. Variables: Measureable, Calculable;
      iv. Eliminating variables (by altering the experiment);
      v. Approximations and assumptions.
      vi. Experiment Outline
   e. Working alone, with a partner, and within a group.
      i. Independent experimentation: observe phenomenon, and then conduct research on their own to produce an evidence-based explanation.

2. Instrumentation
   a. Lab Equipment
      i. sensors and computer interface,
      ii. multimeter,
      iii. signal generator,
      iv. oscilloscope,
      v. Geiger counters,
      vi. microscope,
      vii. smartphones and mobile apps, etc.
   b. Determining instrument precision
   c. instrument calibration
   d. Equipment setup
   e. Determining experimental uncertainties
   f. Videocapture, Particle Tracking, tracking software

3. Data Handling
   a. Measurements: Best Estimate, Uncertainty and Error Bars; Significant Figures
   b. Data Acquisition Software: Capstone
4. Data Analysis
   a. Review data and experiment to determine how the data should be analyzed; determine how many repeated measurements are necessary.
   b. Curve Fits: linear, quadratics and polynomials, exponential, sine (or other oscillatory behavior), etc.; plot linearization
   c. Error Analysis: differences and discrepancies;
      i. error types;
      ii. error propagation;
      iii. statistical analysis of random uncertainties (Repeating measurements, Mean, RMS, Standard Error, sigma);
      iv. identifying systematic errors;
      v. offset bias and other treatments of systematic errors;
      vi. histograms, weighted averages, and least-squares fitting.
   d. Probability Distributions
      i. Normal, Binomial, Poisson;
      ii. Chi-Squared Test and degrees of freedom;
      iii. Rejection of Data
   e. Correlation, Covariance, and Causation; review of approximations and assumptions

5. Results and Conclusions
   a. Determining if experimental evidence is consistent with theoretical predictions.
   b. Drawing conclusions based on experimental evidence.
   c. Using results to guide new experimentation or analysis.

6. Communication
   a. Experiment Documentation
      i. Paper Lab Notebooks;
      ii. Electronic Notebooks (LabArchives)
   b. Scientific Papers
      i. parts of a paper
      ii. reading
      iii. writing
   c. Peer Review Process
   d. Scientific Posters and poster sessions

New course descriptions

**PHYS 1912L. Laboratory Skills for Physicists I.** Fundamental laboratory skills and techniques. Experimental design, instrumentation, data handling and analysis, documentation, presentation of results. Prerequisite: 1501, 1601, 1911 or 2051. Prerequisite or corequisite: 1502, 1602, 1912, or 2053. [1] (MNS)

**PHYS 2255L. Laboratory Skills for Physicists II.** Fundamental laboratory skills and techniques. Experimental design, instrumentation, data handling and analysis, documentation, presentation of results. Prerequisite: 1502, 1602, 1912 or 2053; 1912L or one of 1501L or 1601L and one of 1502L or 1602L. Prerequisite or corequisite: 2255 or 3651. [1] (MNS)
O. Revision of Course Descriptions for Principles of Physics Classes (1901, 1902)

Existing course description of course to be deleted:

**PHYS 1901. Principles of Physics I.** [Formerly PHYS 121A] Classical dynamics, conservation laws, gravitation, wave motion, and thermodynamics. Designed for first-year students who plan to major in physics or in related disciplines. Three lectures and a one-hour discussion period on modern topics of interest. One three-hour laboratory per week. Students who have earned credit for both 1501 and 1501L or both 1601 and 1601L will earn one hour of credit for this course. Students who have earned credit for 1501 or 1601 only will earn two hours of credit for this course. Students who have earned credit for 1501L or 1601L only will earn four hours of credit for this course. Prerequisite or corequisite: MATH 1301 or 2200. [5] (MNS)

**PHYS 1902. Principles of Physics II.** [Formerly PHYS 121B] Continuation of 1901. Electromagnetism, optics, relativity, quantum mechanics, and atomic and nuclear physics. Designed for first-year students who plan to major in physics or in related disciplines. Three lectures and a one-hour discussion period on modern topics of interest. One three-hour laboratory per week. Students who have earned credit for both 1502 and 1502L or both 1602 and 1602L will earn one hour of credit for this course. Students who have earned credit for 1502 or 1602 only will earn two hours of credit for this course. Students who have earned credit for 1502L or 1602L only will earn four hours of credit for this course. Prerequisite or corequisite: MATH 2300 or 2500. [5] (MNS)

New course descriptions, including deletion of lab, change in total credit hours:

**PHYS 1911. Principles of Physics I.** Classical dynamics, conservation laws, gravitation, wave motion, and thermodynamics. Designed for first-year students who plan to major in physics or in related disciplines. Three lectures and a one-hour discussion period on modern topics of interest. Students who have earned credit for 1501, 1601 or 2051 will earn one hour of credit for this course. Corequisite: MATH 1301. [4] (MNS)

**PHYS 1912. Principles of Physics II.** Continuation of 1901. Electromagnetism, optics, relativity, quantum mechanics, and atomic and nuclear physics. Designed for first-year students who plan to major in physics or in related disciplines. Three lectures and a one-hour discussion period on modern topics of interest. Students who have earned credit for 1502, 1602 or 2053 only will earn one hour of credit for this course. Corequisite: MATH 2300 or 2500. [4] (MNS)
P. Revision of Classical Mechanics Instruction from two semesters (2270, 2271) to one semester (2275)

Two current courses, Classical Mechanics I (2270) and Classical Mechanics II (2271) will be combined into a single course, Classical Mechanics (2275). The outline of this new class is presented below. A committee of instructors of these classes from the last decade (Vicki Greene, Richard Haglund, Charlie Maguire, Paul Sheldon) developed the content for this revised course.

<table>
<thead>
<tr>
<th>Class</th>
<th>Theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculus of variations</td>
</tr>
<tr>
<td>2</td>
<td>Hamilton's principle-Lagrangian dynamics</td>
</tr>
<tr>
<td>3</td>
<td>Conservation laws and canonical equations of motion</td>
</tr>
<tr>
<td>4</td>
<td>First application of Lagrangian: orbits in central force field</td>
</tr>
<tr>
<td>5</td>
<td>Effective potentials, Kepler problem and orbital stability</td>
</tr>
<tr>
<td>6</td>
<td>Dynamics of elastic collisions and conservation laws</td>
</tr>
<tr>
<td>7</td>
<td>Applications: Rutherford scattering, falling linear chain</td>
</tr>
<tr>
<td>8</td>
<td>Motion in a non-inertial frame of reference</td>
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<tr>
<td>9</td>
<td>Centrifugal and Coriolis forces</td>
</tr>
<tr>
<td>10</td>
<td>Planar motion of a rigid body and principal axes of inertia</td>
</tr>
<tr>
<td>11</td>
<td>Moments of inertia in different body coordinate systems</td>
</tr>
<tr>
<td>12</td>
<td>Eulerian equations for a rigid body</td>
</tr>
<tr>
<td>13</td>
<td>Application of Euler's equations to the symmetric top</td>
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<tr>
<td>14</td>
<td><strong>This space intentionally left blank</strong></td>
</tr>
<tr>
<td>15</td>
<td>Harmonic oscillator in one and two dimensions technique: Fourier series</td>
</tr>
<tr>
<td>16</td>
<td>The anharmonic oscillator and chaos technique: Perturbation theory</td>
</tr>
<tr>
<td>17</td>
<td>Mapping and classifying chaotic behavior</td>
</tr>
<tr>
<td>18</td>
<td>Coupled harmonic oscillators in the weak-coupling limit</td>
</tr>
<tr>
<td>19</td>
<td>Generalization to many oscillators, orthogonal eigenvectors</td>
</tr>
<tr>
<td>20</td>
<td>Normal modes in coupled systems</td>
</tr>
<tr>
<td>21</td>
<td>Two-state systems in quantum mechanics technique: Two-state Schrödinger system</td>
</tr>
<tr>
<td>22</td>
<td>The linear triatomic molecule and molecular vibrations</td>
</tr>
<tr>
<td>23</td>
<td>From the loaded to the continuous string</td>
</tr>
<tr>
<td>24</td>
<td>Energy of the vibrating string and the wave equation</td>
</tr>
<tr>
<td>25</td>
<td>General solution to the wave equation: forcing and damping</td>
</tr>
<tr>
<td>26</td>
<td>Separation of variables in the wave equation</td>
</tr>
<tr>
<td>27</td>
<td>Wave equation, phase and group velocities, wave packets</td>
</tr>
<tr>
<td>28</td>
<td><strong>This space intentionally left blank</strong></td>
</tr>
</tbody>
</table>
Existing course description of course to be deleted:


**PHYS 2271. Classical Mechanics II.** [Formerly PHYS 227B] Continuation of 2270. Orbital and rotational angular momentum and gravitational and Coulomb central-force problems, motion in non-inertial reference frames; coupled oscillators and normal modes; rigid-body motion; continuous systems and the wave equation; special relativity. Prerequisite: 2270. [3] (MNS)

New course description:

Q. Revision of Modern Physics and the Quantum World course (2250 changed to 2255)

The content for the new course 2255 will include most of what has been taught in prior years in 2250, with the addition of relativity. The model for the course will be the textbook Modern Physics for Scientists and Engineers (fourth edition), by Thornton and Rex, Chapters 1-9.

1. The Birth of Modern Physics
   a. Classical Physics of the 1890s
   b. The Kinetic Theory of Gases
   c. Waves and Particles
   d. Conservation Laws and Fundamental Forces
   e. The Atomic Theory of Matter
   f. Unresolved Questions of 1895

2. Special Theory of Relativity
   a. The Apparent Need for Ether
   b. The Michelson-Morley Experiment
   c. Einstein’s Postulates
   d. The Lorentz Transformation
   e. Time Dilation and Length Contraction
   f. Addition of Velocities
   g. Experimental Verification
   h. Twin Paradox
   i. Spacetime
   j. Doppler Effect
   k. Relativistic Momentum
   l. Relativistic Energy
   m. Computations in Modern Physics
   n. Electromagnetism and Relativity

3. Experimental Basis of Quantum Physics
   a. Discovery of the X Ray and the Electron
   b. Determination of Electron Charge
   c. Line Spectra
   d. Quantization
   e. Blackbody Radiation
   f. Photoelectric Effect
   g. X-ray Production
   h. Compton Effect
   i. Pair Production and Annihilation

4. Structure of the Atom
   a. The Atomic Models of Thomson and Rutherford
   b. Rutherford Scattering
   c. The Classical Atomic Model
   d. The Bohr Model of the Hydrogen Atom
   e. Successes and Failures of the Bohr Model
   f. Characteristic X-ray Spectra and Atomic Number
   g. Atomic Excitation by Electrons

5. Wave Properties of Matter and Quantum Mechanics I
   a. X-ray Scattering
   b. De Broglie Waves
   c. Electron Scattering
   d. Wave Motion
   e. Waves or Particles?
   f. Uncertainty Principle
   g. Probability, Wave Functions and the Copenhagen Interpretation
   h. Particle in a Box

6. Quantum Mechanics II
a. The Schrodinger Wave Equation
b. Expectation Values
c. Infinite Square-Well Potential
d. Finite Square-Well Potential
e. Three-Dimensional Infinite-Potential Well
f. Simple Harmonic Oscillator
g. Barriers and Tunnelling

7. The Hydrogen Atom
   a. Application of the Schrodinger Equation to the Hydrogen Atom
   b. Solution of the Schrodinger Equation for Hydrogen
   c. Quantum Numbers
   d. Magnetic Effects on Atomic Spectra – the Normal Zeeman Effect
   e. Intrinsic Spin
   f. Energy Levels and Electron Probabilities

8. Atomic Physics
   a. Atomic Structure and the Periodic Table
   b. Total Angular Momentum
   c. Anomalous Zeeman Effect

9. Statistical Physics
   a. Historical Overview
   b. Maxwell Velocity Distribution
   c. Equipartition Theorem
   d. Maxwell Speed Distribution
   e. Classical and Quantum Statistics
   f. Fermi-Dirac Statistics
   g. Bose-Einstein Statistics
R. Revisions of Statistical Physics Courses

Because CS 1101 (or equivalent knowledge) will be assumed for all upper-level PHYS classes, we no longer need to distinguish between Statistical Physics (3200) and Computational Statistical Physics (3207). We will simply remove 3207 from the catalog.

We also will change the title of this course to emphasize Statistical Physics (and de-emphasize thermodynamics).

Existing course descriptions of courses to be deleted:


**PHYS 5207. Computational Thermal and Statistical Physics.** (Also listed as PHYS 3207) Temperature, work, heat, and the first law of thermodynamics. Entropy and the second law of thermodynamics. Kinetic theory of gases with applications to ideal gases and electromagnetic radiation. No credit for students who have earned credit for 3200 or 3207. [3]

Existing course descriptions of courses to be revised:


**PHYS 5200. Thermal and Statistical Physics.** (Also listed as PHYS 3200) Temperature, work, heat, and the first law of thermodynamics. Entropy and the second law of thermodynamics. Kinetic theory of gases with applications to ideal gases and electromagnetic radiation. No credit for students who have earned credit for 3200 or 3207. [3]

Revised course descriptions:

**PHYS 3200. Statistical Physics.** Temperature, work, heat, and the first law of thermodynamics. Entropy and the second law of thermodynamics. Kinetic theory of gases with applications to ideal gases and electromagnetic radiation. Prerequisite or corequisite: 2270. Serves as repeat credit for students who have completed 3207. [3] (MNS)

**PHYS 5200. Statistical Physics.** (Also listed as PHYS 3200) Temperature, work, heat, and the first law of thermodynamics. Entropy and the second law of thermodynamics. Kinetic theory of gases with applications to ideal gases and electromagnetic radiation. No credit for students who have earned credit for 3200 or 3207. [3]
S. Changes of Sophomore Year Classes (2250, 2250W, 2260, 2260W) to 2255 and 2953L

Existing course descriptions of courses to be deleted:

**PHYS 2250. Concepts and Applications of Quantum Mechanics.** [Formerly PHYS 225] Atomic and molecular structure, interaction of light with atoms and molecules, and spectroscopy. One three-hour laboratory per week. Repeat credit for students who have completed 2250W. Prerequisite: either 1502 or 1602 or 1902. Prerequisite or corequisite: MATH 2300 or 2500. [4] (MNS)

**PHYS 2250W. Concepts and Applications of Quantum Mechanics.** [Formerly PHYS 225W] Atomic and molecular structure, interaction of light with atoms and molecules, and spectroscopy. One three-hour laboratory per week. Repeat credit for students who have completed 2250. Prerequisite: either 1502 or 1602 or 1902. Prerequisite or corequisite: MATH 2300 or 2500. [4] (MNS)

**PHYS 2260. Modern Physics.** [Formerly PHYS 226] Condensed-matter physics, biophysics, special theory of relativity, and nuclear and particle physics. One three-hour laboratory per week. Repeat credit for students who have completed 2260W. Prerequisite: either 1502 or 1602 or 1902. Prerequisite or corequisite: MATH 2300 or 2500. [4] (MNS)

**PHYS 2260W. Modern Physics.** [Formerly PHYS 226W] Condensed-matter physics, biophysics, special theory of relativity, and nuclear and particle physics. One three-hour laboratory per week. Repeat credit for students who have completed 2260. Prerequisite: either 1502 or 1602 or 1902. Prerequisite or corequisite: MATH 2300 or 2500. [4] (MNS)

New course descriptions:


**PHYS 2953L. Advanced Physics Laboratory: Introduction to Experimental Research.** Fundamental physics experiments and measurements. Statistical analysis of measured data. One three-hour laboratory per week. Prerequisite: 2255L and either 2255 or 3651 or both of 2250W and 2260W. [1] (MNS)

General Description of **Advanced Physics Laboratory: Introduction to Experimental Research** course

In **Advanced Physics Laboratory: Introduction to Experimental Research**, students will work in teams of two, three or four students to conduct five to seven experiments during the semester (some experiments can be finished in one week; others will require two or three weeks to complete). The experiments will be selected from those that enable students to make measurements of fundamental properties of the physical world, including but not limited to the following:

1. Measuring the fundamental constants G and k;
2. constructing and testing a proportional tube detector;
3. using a digital oscilloscope and calibrating the accuracy of oscilloscope measurements;
4. measuring the lifetime of the muon;
5. using a G38eiger counter and a microcontroller to measure and examine the statistics of particle decays;
6. precision gamma-ray spectroscopy, including gamma-ray absorption;
7. positron emission tomography (including gamma coincidence);
8. programming and scripting techniques for data analysis;
9. Faraday rotation and polarization;
10. precision measurement of the acceleration of the Earth (g);
11. studying macroscopic properties of spin;
12. Franck-Hertz experiment (revealing the quantum nature of atoms);
13. measuring the charge-to-mass ratio of the electron;
14. measuring the frequency and damping parameters of a torsional pendulum (the driven, mechanical oscillator);
15. using the Hall probe to measure magnetic forces and interactions;
16. measuring the polarization of light and the rotation of polarization;

Throughout the semester, instruction will be given on hypothesis development, laboratory safety, use of electronic logbooks for storing data and lab reports, data analysis and skills for data taking.

Students will write individually write lab reports for each experiment and will be given opportunities to revise each report. Grades will be based on data taking (33%), first draft lab reports (33%) and final lab reports (34%).
T. Revisions of Other Courses with Changed Prerequisites

- PHYS 2290 (E&M 1) (delete prereq: 1502 or 1602 or 1902; delete prereq: MATH 1301 or 2200; add prereq: 2255 or 3651; add coreq: MATH 2400 or 2420 or 2610)
- PHYS 2291 (E&M 2) (delete prereq: MATH 2400, 2420 or 2610; retain prereq: 2290)
- PHYS 2660 (nano). (delete prereq: 2250 and 2260; add prereq: 2255 or 3651; change prereq: ‘one of 1501, 1601, 1901’ to ‘one of 1501, 1601, 1911, 2051’).
- PHYS 2805 --- will be dropped
- PHYS 3125 (Health physics). (Delete prereq: 2250; add prereq: 2255 or 3651)
- PHYS 3122 (Biophysics) (change ‘1502, 1602 or 1902’ to ‘1502, 1602, 1912 or 2053’)
- PHYS 3640 (Condensed Matter). Change prereq from ‘2250 and 2260’ to ‘2255 or 3651’
- PHYS 3645 (Radiation Detectors) (added prereq: 1502, 1602, 1912 or 2053’)
- PHYS 3651 (QM 1) (Change prereq from 2250 and 2260’ to ‘2255 or 3651’)
- PHYS 3660 (particle phys) Change prereq from ‘2250 and 2260’ to ‘2255 or 3651’
U. Issues Created for Current Students

We have identified a number of issues for current students, for which we also propose solutions. Until all students from the Class of 2020 (and before) graduate, we will have to support alternatives to the proposed new rules that allow these students to graduate using the currently-in-place rules for the physics major.

1. Problem: split of 1901 into 1911 and 1912L.
   Solution: Students can take both 1911 and 1912L.

2. Problem: split of 1902 into 1912 and 2255L.
   Solution: Students can take both 1912 and 2255L.

3. Problem: elimination of required course 2250/2250W.
   Solution: replace 2250 with PHYS 2255 + 2293L.

4. Problem: elimination of required course 2260/2260W.
   Solution: Use any 4 credit hours of 2000-level or above course work or 3 credit hours of 2000-level or above course work and one credit hour of research in place of 2260

5. Problem: requirement to take three-semester laboratory sequence.
   Solution: current students are exempt from this rule. The separation of the 1901/1902/2250 labs and the elimination of the 2260 lab will not negatively affect them.

6. Problem: elimination of 2000-level PHYS course that satisfies 2000-level W requirement for AXLE
   Solution: student will have to complete AXLE ‘W’ requirement outside of PHYS classes

7. Problem: elimination of the one-credit astronomy seminar ASTR 2600;
   Solution for PHYS majors graduating under the old rules: allow students to substitute any one credit hour from any 2000-level or higher elective course or research.
   Solution for ASTR minors (who must take ASTR 2600 twice): waive the ‘take twice’ requirement.

8. Problem: combining 2270 and 2271 into a single-semester course.
   Solution: require Classical Mechanics, 2275, instead of 2270. 2271 was an elective, so elimination is not a problem that requires a solution.

   Solution: currently an elective, so the increased difficulty is not a problem that requires a solution.

10. Problem: change in structure of 3600 (seminar)
    Solution: all students can continue to take revised version of 3600.

11. Problem: requiring research for all majors.
    Solution: current students are exempt from this requirement.

12. Problem increase from 3 to 9 credit hours in required electives in regular course work.
    Solution: current students are exempt from this requirement.

13. Problem: change in expectations for CS knowledge in all courses
    Solution: most students have taken CS 1101. Encourage all current students to do so, but faculty will have to offer current students without CS backgrounds alternative problems or exam questions or projects.
V. Courses to be Deleted from the Catalog

1. PHYS 1901: Principles of Physics I
2. PHYS 1902: Principles of Physics II
3. PHYS 2237: Computational Physics
4. PHYS 2250: Concepts and Applications of Quantum Mechanics
5. PHYS 2250W: Concepts and Applications of Quantum Mechanics
6. PHYS 2260: Modern Physics
7. PHYS 2260W: Modern Physics
8. PHYS 2270: Classical Mechanics I
9. PHYS 2271: Classical Mechanics II
10. PHYS 2805: Foundations of Medical Imaging
11. PHYS 3207: Computational Thermal and Statistical Physics
12. PHYS 5207: Computational Thermal and Statistical Physics
13. PHYS 3840 and ASTR 3840: Directed Study.
14. PHYS 3860 and ASTR 3860: Independent Study.
15. ASTR 2600: Undergraduate Seminar
### W. Number of Physics Majors and Honors candidates, 1992-present

The following lists the number of physics majors graduating each year, with the number of those students completing Honors in Physics or Honors in Astronomy noted in parantheses:

<table>
<thead>
<tr>
<th>Class</th>
<th>Physics Majors</th>
<th>Honors in Physics</th>
<th>Honors in Astronomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class of 1992</td>
<td>9 ( ?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 1993</td>
<td>8 ( ?)</td>
<td></td>
<td></td>
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<tr>
<td>Class of 1994</td>
<td>9 (1)</td>
<td></td>
<td></td>
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<tr>
<td>Class of 1995</td>
<td>9 (1)</td>
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<td></td>
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<tr>
<td>Class of 1996</td>
<td>5 (1)</td>
<td></td>
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<tr>
<td>Class of 1997</td>
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<td>Class of 1998</td>
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<td>Class of 1999</td>
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<td>Class of 2000</td>
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<td>Class of 2001</td>
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<tr>
<td>Class of 2002</td>
<td>5 (0)</td>
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<tr>
<td>Average 1992-2002</td>
<td>8 (1)</td>
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<tr>
<td>Class of 2003</td>
<td>10 (2)</td>
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<tr>
<td>Class of 2004</td>
<td>10 (5)</td>
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<tr>
<td>Class of 2005</td>
<td>12 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2006</td>
<td>13 (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2007</td>
<td>11 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2008</td>
<td>14 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2009</td>
<td>12 (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average 2004-2009</td>
<td>12 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2010</td>
<td>17 (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2011</td>
<td>13 (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2012</td>
<td>14 (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2013</td>
<td>12 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2014</td>
<td>11 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2015</td>
<td>11 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2016</td>
<td>18 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2017</td>
<td>16 (5)</td>
<td></td>
<td>--- anticipated</td>
</tr>
<tr>
<td>Average 2010-2016</td>
<td>14 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2018</td>
<td>13 (declared juniors)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2019</td>
<td>unknown (current sophomores; 7 declared as of now)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class of 2020</td>
<td>unknown (current first-years; 1 declared as of now)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
X. Number of Physics Minors, 2008-present

The following lists the number of physics minors graduating each year, with the students’ majors or schools in parantheses:

Class of 2008: 0
Class of 2009: 1
Class of 2010: 1
Class of 2011: 0
Class of 2012: 1
Class of 2013: 1
Class of 2014: 2 (BME, German/premed)
Class of 2015: 1 (psych)
    Average 2008-2015: 1
Class of 2016: 4 (3 engineers, 1 math)
Class of 2017: 3 declared (BME, EE, MATH)
Class of 2018: 2 declared (CS, Math)
Class of 2019: 2 declared (EE, undeclared ENG)
    Average 2016-2019: 3

Y. Department Vote of Approval of this Proposal

Following a Departmental meeting held on November 7, 2016, the faculty voted by email ballot to approve all of the recommendations (the revised Physics major; the revised Physics minor; the revised Astronomy minor; the deletions, title changes, and revised descriptions of existing courses; the creation of the necessary new courses) detailed in this report by a vote of 17-0 (1 abstention).