Proposal for Revising the Undergraduate Physics Curriculum Version 1.11

Undergraduate Curriculum Committee

November 18, 2020

1 Changes Since the Faculty Meeting

A number of changes have been made to the proposal, based on discussion and feedback following the presentation of this proposal to the faculty on June 3, 2020. Those changes include:

- The new course PHY 115C is no longer a required course.
- Symbolic Computation has been added to PHY 40.
- Example syllabi for required courses impacted by this proposal are now included.
- Proposed revisions to the Astrophysics and Applied Physics majors are now included.
- Some prerequisites were changed to accommodate the additional majors.

2 Objectives of the Proposal

An example schedule of student course work without the revisions proposed here is shown in Table 1 for students taking honors physics. An example schedule for students that transfer to UC Davis for their junior year is shown in Table 2. There are many different trajectories through our program, but most are some variation on these two. For consistent comparisons, all the example schedules in this proposal assume the students take 122A and one capstone course in the winter, and two capstone courses in the spring. Many other lab courses and offerings are possible. There are some deficiencies in the current course of study:

- Physics majors who complete 9HD or 9D in the fall of their sophomore year have little to do for the rest of the year. The honors sequence has 9HE, but this is effectively an elective and does little to further prepare students for upper division course work. The recent addition of 40 and 80 is helpful in that it provides something for students to do during this time, but the problem still remains that they do not make progress on the upper division core course work, and 80 is not taken by all students. The result of this stalling is that the junior and senior year are a race to complete the degree requirements, leaving very little flexibility or time for advanced electives.

Table 1: An example schedule for an undergraduate physics major that takes the 9H series and 122A. Physics course numbers are shown with the number of units in parenthesis. Math courses start with M. Taking MAT 21A in fall is also common with instructor permission, with MAT 21D taken over the summer to catch up in time for 9HD. Courses in italics are electives or have at least two different offerings per year. Course CAP is a capstone elective, and course X is any advanced elective.

Year	Fall	Winter	Spring
Freshman	9HA(5) *M21B(4)*	9HB(5) *M21C(4)*	9HC(5) *M21D(4)*
Sophomore	9HD(5) *M22A(3)*	9HE(5) *M22B(3)*	40(4) *80(4)*
Junior	104A(4) 105A(4) 102(1)	105B(4) 110A(4)	110B(4) 115A(4)
Senior	110C(4) 112(4) 115B(4)	*122A(4)* *CAP(4)* *CAP(4)*	*X(3-4)* *X(3-4)* *CAP(4)*

Table 2: An example schedule for undergraduate physics major that transfers to UC Davis in their junior year and takes 122A. Physics course numbers are shown with the number of units in parenthesis. Courses in italics are electives or have at least two different offerings per year. Course CAP is a capstone elective, and course X is any advanced elective. Note that PHY 102 is generally considered to be much more work than a typical one-unit course.

Year	Fall	Winter	Spring
Junior	9D(4) 104A(4) 105A(4) 102(1)	105B(4) 110A(4) *80(4)*	40(4) 110B(4) 115A(4)
Senior	110C(4) 112(4) 115B(4)	*122A(4)* *CAP(4)* *CAP(4)*	*X(3-4)* *X(3-4)* *CAP(4)*

- Students that transfer to UC Davis for their junior year face a wall of course work that they have to handle in the first quarter: math methods, mechanics, and modern physics. Many also take 102, which is nominally a one-unit course, but generally nearly as much work as a four-unit course. For many students, these are also the first courses they encounter that require solving challenging homework problems. We have two trains of students running through our program and the fall of their junior year is the train wreck where they collide.

- The current curriculum does not include sufficient computing practice for our students. It is useful to consider what a physics degree would look like if we taught calculus the same way we teach computing. Students would arrive their freshman year and take an introductory calculus course. Then, they would take their physics courses, which would never mention calculus. At some point in their junior or senior year, they would take a one quarter course called "Calculus in Physics" which would attempt to show all the ways we use calculus in physics. Our students are experts at calculus because they learn how to use the tool, and then apply it, again and again, throughout their course work. To remain relevant in the modern world (or even the world from 20 years ago) our majors need more practice in the use of computing as an essential tool for solving physics problems.

- Four-year students typically graduate with around 180 units. Within the College of Letters and Science, we are allowed to require a maximum of 110 units in our majors. The current BS physics major requires a minimum of 108 units to complete. Fitting the canon of undergraduate physics into such a tight space is extremely challenging. Students complain that we waste time teaching some topics again and again (e.g. Special Relativity from scratch) while completely dropping other topics (e.g. Classical Hamiltonians). The problem is particularly acute for applied physics majors, where core material must be dropped to make space for course work outside of physics.

- The prerequisite structure of the upper division courses creates many tiers. As an extreme example, 122 requires 112, which requires 115A, which requires 104A and 105A, both of which require the 9 series. This, combined with the rapid pace, leaves very little flexibility for students once they start their junior year. For example, missing any of the four-unit courses in the junior year of Table 1 requires an exception to prerequisites or an extra year to graduate.

This proposal aims to make significant improvements on each of these issues.

3 Proposed BS Requirements

The proposed required courses for a BS in physics are presented in Tables 3 and 4. Example schedules are presented in Tables 5-7.

A primary feature of this proposal is that incoming transfer students now overlap in some courses with sophomores that took the honors physics sequence. This eliminates the stalling of our four-year students while relieving some of the intense academic pressure on incoming transfer students. Our experience has been that the best of our transfer students perform as well as the best of our four-year students, once they have sufficient time to adjust, and this proposal gives them that time. Accelerating students that took the honors sequence also provides tremendous additional flexibility to their schedule.

Transfer students that wish to complete their degree in two years are still highly constrained, but instead of facing three upper division courses immediately upon arrival they now start with one upper division course. Take the time to compare fall quarter of the junior year in Tables 2 and 7, this is a major feature of this proposal. This gentle introduction does not come at the cost of dramatically increased unit loads later on: transfer students can still complete the degree without exceeding 13 units of physics course work in any quarter.

Table 3: Preparatory Subject Matter

Units: 53-54. *: recommended, || concurrently.

Course		Units	Offered	Prereqs	Name
MAT	21A	4	FWS		Differential Calculus
	21B	4	FWS	21A	Integral Calculus
	21C	4	FWS	21B	Partial Derivatives and Series
	21D	4	FWS	21C	Vector Analysis
	22A	3	FWS	21C	Linear Algebra
	22B	3	FWS	22A	Differential Equations
PHY	9A	5	FS	21B	Classical Physics *(Class. Mech.)*
	9B	5	FW	9A,21C	Classical Physics *(Waves, Thermo., Optics.)*
	9C	5	WS	9B,21D	Classical Physics *(Elec. and Magn.)*
	9D	4	FS	9C,22A	Modern Physics *(Rel. and Quant. Mech.)*
	or				
PHY	9HA	5	F	||21B/21M	Honors Physics *(Class. Mech.)*
	9HB	5	W	21B/21M	Honors Physics *(Rel. and Stat. Mech.)*
	9HC	5	S	21C	Honors Physics *(Waves and Quant. Mech.)*
	9HD	5	F	21D	Honors Physics *(Elec. and Magn.)*
PHY	40	4	F		Introduction to Physics Computation
	45	4	W	40,9C/9HD,||22B	Computational Physics
	80	4	WS	40,9C/9HD	Experimental Techniques
PHY	185*	1	S		Careers in Physics
	190*	1	F		Careers in Physics

Table 4: Depth Subject Matter

Units: 42-46. *: recommended, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	104A	4	FS	9C/9HD,MAT 22B	Mathematical Physics
	105A	4	W	9C/9HD,‖MAT 22B	Classical Mechanics I
	105B	4	S	105A,40	Classical Mechanics II
	110A	4	W	104A	Electricity and Magnetism I
	110B	4	S	110A,9HD/‖9D	Electricity and Magnetism II
	112	4	F	104A,9D/9HD	Thermodynamics and Stat. Mech.
	115A	4	F	104A,105A,9D/9HD	Quantum Mechanics I
	115B	4	W	115A	Quantum Mechanics II
	115C*	4	S	115B,45	Applications of Quantum Mechanics
PHY	116A	4	F	80	Phys. Instr. with A&D Electronics.
	116B	4	W	80	Phys. Instr. for Data Acquisition.
	or				
PHY	122A/B	4	WS	80,104A,105A,110B & ‖112 ‖115A	Advanced Physics Laboratory
	Any two of				(all three recommended):
PHY	110L	1	S	45/ECS 36B, ‖110B	Comp. Lab in Electricity and Magn.
	112L	1	F	45/ECS 36B, ‖112	Comp. Lab in Statistical Mechanics
	115L	1	W	45/ECS 36B, ‖115B	Comp. Lab in Quantum Mechanics

Electives: Additional electives to bring the total number of 3-4 unit upper division courses to 14, including at least three from capstone courses. (3-4 courses, totaling 12-16 units with current offerings)

Total Units: 110-112

Table 5: An example schedule for an undergraduate physics major that takes the 9H series and 122A. Physics course numbers are shown with the number of units in parenthesis. Math courses start with M. Courses in italics are electives or have at least two different offerings per year. Course CAP is a capstone elective, and course X is any advanced elective. Rate is 3-9 physics units per quarter in junior and senior year.

Year	Fall	Winter	Spring
Freshman	9HA(5) *M21B(4)*	9HB(5) *M21C(4)*	9HC(5) *M21D(4)*
Sophomore	9HD(5) *M22A(3)* 40(4)	105A(4) *M22B(3)* 45(4)	105B(4) *104A(4)* *80(4)*
Junior	115A(4) 112+L(5)	115B+L(5) 110A(4)	*115C(4)* 110B+L(5)
Senior	*X(3-4)*	*122A(4)* *CAP(4)*	*CAP(4)* *CAP(4)*

The college imposes a limit of 110 units of required course work, including prerequisites, for any major. Within a particular major, options that exceed this limit are permitted, as long as a path that stays below the limit is available. The current BS physics major requires a minimum of 108 units. This proposal takes advantage of the remaining two units and brings the minimum to 110 units. This slightly increases total unit pressure on students, which particularly affects those transfer students who have only two-years to absorb them. However, the proposal replaces the one-unit course PHY 102 with the more accurately credited four-unit PHY 45 course. Also, the major stress point for transfer students is in in their first quarter, which this proposal substantially improves. The proposal also adds significantly more schedule flexibility, which should also help alleviate pressure.

Table 6: An example schedule for an undergraduate physics major that takes the 9 series and 122A. Physics course numbers are shown with the number of units in parenthesis. Math courses start with M. Courses in italics are electives or have at least two different offerings per year. Course CAP is a capstone elective, and course X is any advanced elective. Rate is 7-13 physics units per quarter in junior and senior year.

Year	Fall	Winter	Spring
Freshman	*M21A(4)*	*M21B(4)*	*M21C(4)* *9A(5)*
Sophomore	*M21D(4)* *9B(5)* 40(4)	*M22A(3)* *9C(5)*	*M22B(3)* *9D(4)* *80(4)*
Junior	*104A(4)* *X(3-4)*	105A(4) 110A(4) 45(4)	105B(4) 110B+L(5)
Senior	115A(4) 112+L(5)	115B+L(5) *122A(4)* *CAP(4)*	*115C(4)* *CAP(4)* *CAP(4)*

Table 7: An example schedule for an undergraduate physics major that transfers to UC Davis in their junior year, without Physics 9D or 40 equivalents, and takes 122A. Physics course numbers are shown with the number of units in parenthesis. Courses in italics are electives or have at least two different offerings per year. Course CAP is a capstone elective, and course X is any advanced elective. Rate is 12-13 units per quarter. Note that only one upper division course is required in the first quarter of junior year, compared to three upper division courses in the current program.

Year	Fall	Winter	Spring
Junior	9D(4) 40(4) *104A(4)*	105A(4) 110A(4) 45(4)	105B(4) 110B+L(5) *80(4)*
Senior	115A(4) 112+L(5) *X(3-4)*	115B+L(5) *122A(4)* *CAP(4)*	*115C(4)* *CAP(4)* *CAP(4)*

Several new courses have been added, some are no longer offered, and others require changes to their content:

- 9A-D and 9HA-D are largely unchanged, however, some fine adjustments may be needed to ensure that the 9 series plus 104A are sufficient preparation for 112. Also, there are some minor adjustments to the math prerequisites.
- 9HE is no longer offered. This course is effectively an elective, with content that varies from instructor to instructor. By removing it, we allow the students in the honors sequence to start toward the core material sooner, leaving more time for advanced electives. With the more relaxed schedule in their senior year, it seems highly plausible that physics majors will take more advanced electives.
- 104A: This course will now be offered in both fall and spring, as discussed further in the discussion of prerequisites. Most students taking honors physics will take the course in the spring, while most transfer students will take the course in the fall. Two offerings will remove a major bottleneck, result in smaller class sizes, and will allow the course to be pitched slightly differently in these two quarters, to better reflect student preparation.
- 105: The timing of the 105AB sequence is adjusted to start in winter. The content of 105AB should be at a level appropriate for a sophomore completing 9HD in the previous quarter. There is no prerequisite for 104A, but typically students will take 104A either concurrently with 105B or before 105A.
- 110: The present curriculum devotes three quarters of required upper division course work to Electricity and Magnetism (110ABC). This proposal eliminates 110C and increases the pace of 110AB. Students must reliably enter 110 having adequate preparation in vector calculus, curvilinear coordinates, Lorentz transformation, relativisitic mechanics, and introductory electricity and magnetism. This material must be covered adquately in the 9 series and 104A. The sequence will drop guided waves and radiation of moving charges, as well as simplify or skip less critical material. Note that wave guides are an example topic for 110L.
- 112: The 115A prerequisite for 112 has been removed, and the treatment must rely on quantum from the 9 series instead.
- The 115AB sequence is extended to include an elective third quarter: 115C. The prerequisites are 104A and 105A. The elective third quarter, 115C, adds 45 as a prerequisite, and the course includes extensive computational problems. The extra time should also allow coverage of new elective topics (for example Quantum Information Theory).
- New computational physics courses 45, 110L, 112L, and 115L replace the present requirement for 102 or 104B. PHY 45 is a required four-unit course students are required to take at least two of the three one-unit computing lab courses. This is discussed in detail in Section 4.
- The 116ABC sequence adds PHY 80 as a prerequisite and is reduced to a two quarter sequence 116AB. Due to the significant overlap between 116A+116C and 80, no material is lost. This is discussed in detail in Section 5.

Example syllabi for the new required courses and existing courses affected by this proposal are presented in Section 10.

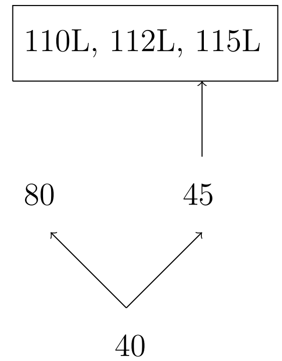

Figure 1: Prerequisite structure of computational courses.

This proposal is approximately neutral with respect to the cost of instruction if we assume that the cost of electives is held constant (we of course have no obligation to do so.) The second offering of 104A, the new required course 45, and the new required one unit computing labs add a total of three new instructors. But dropping courses 9HE, 102, 104B, 110C and 116C frees 4.3 instructors, for a net decrease of 1.3 instructors. If the need for more sections of 80 increases requires an additional instructor (currently typically two, although three were initially planned for 2020-2021) there would be a decrease of 0.3 instructors. Additional fall offerings for 122A/B could be added as well, if needed to meet demand.

4 Computational Physics

One of the major objectives of this proposal is to better integrate computational physics throughout the curriculum. To do so, students must have a consistent set of tools that can be relied upon in later courses. The course descriptions in the course catalog will not reference specific tools, to allow this to evolve over time, but in a consistent manner. In this proposal, the supported computational tools are:

- Scientific computing tools for Python: NumPy, SciPy, MatPlotLib, and Juypter Notebooks via Anaconda
- C/C++
- Computer Algebra: Mathematica or SymPy

The entire Scientific Python ecosystem is easily accessible to students for any major OS for free through Anaconda. No graphical features of C/C++ will be explored. If necessary, C++ programs will pass data by text file to SciPy for plotting. SymPy is not as mature as Mathematica, but comes with the significant advantages of being freely available within Anaconda and interoperable with SciPy.

In response to the ECS department's decision to no longer offer ECS 30, a one quarter introduction to C without any prerequisites, we replaced this required course with own version, PHY 40, in 2018. This course currently introduces programming with both C++ and python. This leaves no time for symbolic computation and little time for exploring additional features of Scientific Python beyond the Python language. The proposal keeps 40 as a physics-centric introduction to programing and adds a second, more advanced computational course, PHY 45, with both 40 and the 9 series as prerequisites. The proposal adds upper division computing labs as well. The computational courses added or impacted by this proposal are:

- 40: This four-unit course has no prerequisites and assumes no prior knowledge of programming. It is primarily an introduction to programming but using examples from computational physics. It will also include a short introduction to symbolic manipulations using a computer algebra system. The specific tools covered (which will not be included in the course description) are Scientific Python and either SymPy or Mathematica.
- 45: This new four-unit course, Computational Physics, will have the PHY 9 series through E&M as a prerequisite (9C/9HD) as well as PHY 40. PHY 45 will replace the requirement for 102 or 104B. The focus will be on solving physics problems at the conceptual level of the 9 series using computational physics. It will introduce the C++ programming language and continue using Scientific Python.
- 80: is a new four-unit lab course introduced in 2018 which includes extensive use of scientific python for data analysis and presentation, including curve fitting and plotting scientific data. In this proposal, 80 is required for all majors and adds 40 as a prerequisite.
- 110L, 112L, and 115L: These three new one-unit computational lab courses are designed to be taken concurrently with 110B, 112, and 115B. They are computational problem solving labs related to E+M, statistical mechanics, and quantum mechanics. The emphasis will be on solving problems from upper division physics using computing at the level of PHY 45. The instructor will present a technique and problem during a single one hour lecture, and the students will have the rest of the week to complete the assignment. One instructor could teach all three of these courses in a single year, which will count as one course. Each course is offered in a different quarter, so students get three units of computational problem-solving spread across an entire year. Due to unit limits, we only require two of these courses, but all three are recommended.
- 105B: this course now has PHY 40 as a prerequisite and can therefore include computational problems in mechanics using Scientific Python or computer algebra.
- 115C: This new elective course has PHY 45 as a prerequisite and is intended to include extensive computational problem solving as an integral part of the course.

Physics BS majors will be required to take 18 units (23 recommended) of course work that involves extensive computing exercises. Furthermore, once student computing abilities are on more solid ground, capstone and advanced elective courses could further evolve to include additional computing exercises and add 45 (or at least 40) as a prerequisite.

5 Lab Course Work

Physics 80 was introduced in 2018, and is currently a prerequisite for 122A/B. It is anticipated that this will relieve some of the intense time pressure in these courses. This proposal makes some adjustments to the prerequisites of 122A/B which would allow for a fall offering if needed to satisfy demand.

In this proposal, Physics 80 is also added as a prerequisite for the 116 (Instrumentation) sequence as well. Physics 80 covers some of the content in current versions of 116A (passive analog electronics)

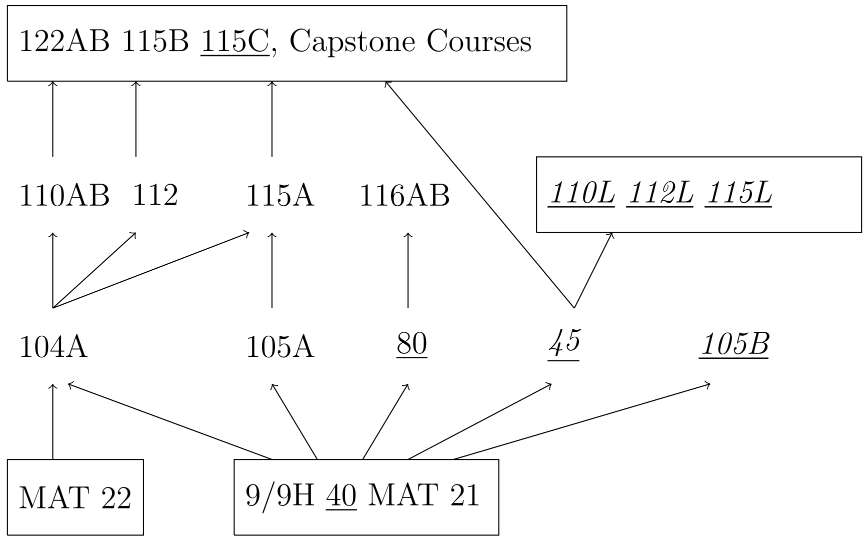

Figure 2: The prerequisite structure of physics and related math courses. Courses within a box may have an internal prerequisite structure not shown. For clarity, in some cases only the most advanced prerequisites are shown. Prerequisites within a sequence (e.g. 112L has concurrent prerequisite with 112) are not shown. All required courses are shown. Underlined courses have a significantly computational component. Italicized courses are required for a BS in Physics but can be safely omitted from the Astrophysics or Applied Physics majors, as they do not serve as prerequisites for other required courses in those majors.

and 116C (computation with scientific python and statistical analysis). Therefore, the three quarter 116 sequence (A,B, and C) becomes a two quarter sequence, with 116A covering analog and digital electronics, and 116B covering data acquisition with microprocessors and FPGAs. For additional flexibility, 116B no longer has 116A as a prerequisite, as sufficient analog electronics is covered in 80.

Physics 80 and 116 share the same dedicated lab space. The primary time for taking 80 will be in spring quarter, but it will also be offered in fall, and possibly winter, while 116A and 116B will be offered in fall and winter respectively.

6 Prerequisites

An overview of the prerequisite structure is shown in Fig. 2. The graph reveals 104A as a major bottleneck in our program, as it requires the most advanced material from the first tier (MAT 22) but is required for most upper division classes, such as 110A and 115A. The committee spent a great deal of time considering different ways to relieve or accommodate this bottleneck but in the end decided two offerings is the only effective way to achieve the goals of this proposal. This stems from the fact that incoming transfer students must start on 104A immediately upon arrival in fall to complete the remaining upper division courses in two years, but sophomores finishing 9HD in the fall are not generally ready to take 104A until the spring.

It appears from the graph that 45 is a bottleneck as well, but it is less severe. It does not require MAT 22A so can be taken sooner than 104A, and it is only needed for top tier courses such as 115C and the computational lab courses, which can be postponed until senior year.

The most notable changes to the prerequisite structure are:

- 80 adds 40 as a prerequisite.
- 112 does not require 115A anymore, 104A and 9A-D must suffice instead.
- 110A does not require 105A anymore.
- 105B requires 40, so computational examples can be used in this course.
- 122A/B adds a 115A prerequisite, which was implicit when 115A was a prerequisite for 112. Both 112 and 115A are allowed to be concurrent, which will not be possible unless we add a fall offering of 122.

The new prerequisite structure is considerably more flexible. In the junior year of Tables 6 and 7 missing or failing 104A or 105A jeopardizes a timely graduation, but instructor permission from one course (110A or 115A) will allow the student to proceed on schedule. The situation in Table 5 is even more forgiving.

7 Capstones and Electives

Because 115A will be taught in the fall instead of spring, capstone courses with 115A as a prerequisite should start in the winter, with a second quarter in spring. We should take care to offer sufficient electives (without a 115A requirement) in fall. We might want to consider a 3-unit upper division course dedicated to our arriving transfer students in the fall, which will focus on consolidation and problem solving from the 9 series. This could also be recommended for students that performed marginally in the 9 series.

8 Proposed BS with Specialization in Astrophysics

The Astrophysics specialization requires updates to the prerequisites for PHY 151-158, mainly to accommodate the new schedule which offers PHY 105A in the fall and to add PHY 40 as a new required course. The Astrophysics specialty courses now include 158, for a total of five, from which four are chosen. Limits on the number of units precludes including PHY 45, and the related lab courses, to the program. However, the PHY 151-158 courses have already begun to include extensive computational physics directly related to astrophysics.

The proposed required courses for the Astrophysics specialization are presented in Tables 8 and 9. To avoid version conflicts, some information in Tables 3 and 4 is not duplicated in these tables. Example schedules are presented in Table 10.

Table 8: Preparatory Subject Matter: Astrophysics and Applied Physics

Units: 49-50. *: recommended, ‖: concurrently.

Course		Units
MAT	21A	4
	21B	4
	21C	4
	21D	4
	22A	3
	22B	3
PHY	9A	5
	9B	5
	9C	5
	9D	4
	or	
PHY	9HA	5
	9HB	5
	9HC	5
	9HD	5
PHY	40	4
	80	4
PHY	185*	1
	190*	1

Table 9: Depth Subject Matter: Astrophysics

Units: 60-64. *: recommended, #: not offered every year, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	104A	4			
	105A	4			
	108	3	S	9D/9HD	Optics
	108L	1	S	‖108	Optics Laboratory
	110A	4			
	110B	4			
	112	4			
	115A	4			
	115B	4			
PHY	157	4	S#	(Same as 122A/B)	Astronomy Instrumentation and Data Analysis Lab
	or				
PHY	122A/B	4			Advanced Physics Laboratory
	Choose four of				
PHY	151	4	F#	‖40,‖104A	Stellar Structure and Evolution
	152	4	F#	‖40,‖104A	Galactic Structure and the Interstellar Medium
	153	4	W#	40,104A,‖105A	Extragalactic Astrophysics
	156	4	W#	40,104A,‖105A	Introduction to Cosmology
	158	4	S	40,104A,105A	Galaxy Formation
	Any two of				:
PHY	105B	4			
	116A	4			
	116B	4			
	129A	4			
	130A	4			
	130B	4			
	150	4			Special Topics
	154	4	S#	40,105B,110B,115A	Astro. Appl. of Phys.
	155	4	W	104A,105B,110A	General Relativity
GEL	163	4			Planetary Geology and Geophysics
	At most one of				
PHY	194HAB	8			Special Study for Honors Students
	195	5			Senior Thesis
	199	4-5			Special Study for Adv. Undergrads.

Note: PHY108 has alternative prerequisites (PHY 7C and 21D) intended for non-majors. PHY 150 must be an astro topic and requires prior department approval.
Total Units: 109-114

Table 10: An example schedule for the junior and senior year of an Astrophysics major. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives. In most cases, the 9D requirement is satisfied before the junior year. The upper table starts with PHY 151 and the lower with 152.

Year	Fall	Winter	Spring
Junior	40	105A	80
	104A	110A	110B
	151#	153#	*105B/150*
	(9D)		
Senior	115A	115B	108+L
	152#	156#	157/122A/B
	112	*130A/155/GEL 163*	*158#/129A/130B*

Year	Fall	Winter	Spring
Junior	40	105A	80
	104A	110A	110B
	152#	156#	*105B/158#*
	(9D)		
Senior	115A	115B	108+L
	151#	153#	157/122A/B
	112	*130A/155/GEL 163*	*154#/129A/130B*

9 Applied Physics

The Applied Physics majors require the preparatory courses in Table 8 and the depth courses listed in Table 11. Together, these required courses account for 73-74 units, leaving 37 credits for concentration courses as detailed in the following tables. This proposal includes modifications to all of the Applied Physics majors:

- All Applied Physics majors now require PHY 40, 45, and 80, two computing labs (from 110L,112L, and 115L), and two upper division lab courses (from 122A/B, 116A, and 116B), except where noted.
- The Computational Physics major does not require PHY 45 and ECS 36B now satisfies the prerequisite for the computing labs. The elective choices from ECS have been extended. See Table 12.
- The Physical Electronics major does not include 116AB as part of the upper division lab requirement, only 122A/B is required. The major includes a large amount of electronics from the EEC department. Due to unit limits, only one computational lab is required. See Table 13.
- The elective choices for the Materials Science major have been extended. Students may use one EMS lab course to satisfy their requirement for two upper division lab courses. See Table 14.
- In the past, the Atmospheric Physics major required the Physical and Chemical Oceanography course (GEL 150A), which now has extensive prerequisites that would exceed the unit limit. The Oceanography thrust of this course has been relocated to the electives, including the more easily obtained (GEL 116N). The list of Atmospheric Physics electives has been extended. See Table 15.
- The Physical and Chemical Oceanography course (GEL 150A) is not offered every year and now has extensive prerequisites. Therefore, the Physical Oceanography major might not be achievable in two years for students that have not already satisfied these prerequisites. The prerequisites for reaching GEL 150A are now included in the concentration courses, and GEL 150B has been added. See Table 16.
- The Chemical Physics major requires 15 credits of lower division General Chemistry course work which severely limits the number of upper division course that can be required in this major. The course requires 115B and 140A as concentration courses. See Table 17.

Table 11: Depth Subject Matter: All Applied Physics Majors

Units: 24.

Course		Units
PHY	104A	4
	105A	4
	110A	4
	110B	4
	112	4
	115A	4

Table 12: Computational Physics

Concentration Courses:
Units: 29 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
ECS	36A	4	FWS		Programming and Problem Solving
	36B	4	FWS		Software Dev. and OOP in C++
	36C	4	FWS		Data Structures, Algorithms, and Programming
	122A	4	FWS		Algorithm Design & Analysis
	Choose one of				
	110L	1			
	115L	1			
	112L	1			
	Choose one of				
ECS	120	4	FWS		Theory of Computation
	122B	4	WS		Algorithm Design & Analysis
	132	4	FWS		Probability & Stat Modeling
	171	4	F		Machine Learning
	Choose two of				
PHY	122A/B	4			
	116A	4			
	116B	4			

Additional Electives: (8 units) Two courses for a total of at least 8 units of additional upper division course work from ECS, MAT, or PHY.
Total Units: 110-111
Example schedules: In most cases, the 9D requirement is satisfied before junior year, but an example including 9D is included. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	ECS 36A 40 104A	ECS 36B 105A 110A	ECS 36C 80 110B+L (9D)
Senior	ECS 122A 112 115A	*ECS 122B/120/132* *116B* *140A*	122A *140B*

Table 13: Physical Electronics

Concentration Courses:

Units: 37 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
ENG	17	4	FWS		Circuits I
EEC	100	4	FW		Circuits II
PHY	45	4			
	115B*	4			
	140A	4			
	140B*	4			
	122A/B	4			
	Choose one of				
	110L	1			
	115L	1			
	112L	1			
	Choose four of				
EEC	110A	4	WS		Electronic Circuits I
	110B	4	S		Electronic Circuits II
	140A	4	FW		Principles of Device Physics I
	140B	4	S		Principles of Device Physics II
	150A	4	WS		Intro. to Signals & Systems I
	150B	4	F		Intro. to Signals & Systems II

Total Units: 110-111

Example schedules: for the junior and senior year. In most cases, the PHY 9D and ENG 17 requirement is satisfied before the junior year, but the first example shows how those courses can be accommodated. The second example considers a student that completed PHY 9HD,40,45,80, 105A and ENG 45 prior to their junior year. A particular feature of this major is the ability to take graduate courses in the senior year. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	(ENG 17) 40 104A	EEC 100 45 110A 105A	(9D) 80 110B+L
Senior	112 115A *EEC 140A*	140A *EEC 110A* *EEC 150A*	122A/B *EEC 110B* *EEC 245/249*
Junior Junior	104A EEC 100	110A *EEC 110A* *EEC 140A*	110B+L *EEC 110B* *EEC 140B*
Senior	112 115A *EEC 210/240*	140A 115B *EEC 212/243*	140B 122A/B *EEC 245/249*

Table 14: Materials Science

Concentration Courses:
Units: 37-38 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	45	4			
	115B	4			
	140A	4			
	140B	4			
ENG	45	4	FWS		Properties of Materials
	Choose two of				
	110L	1			
	115L	1			
	112L	1			
	Choose two of				
EMS	162	4	W		Structure & Characterization
	160+164	7	F+W		Thermo+Kinetics
	170	4	S		Sustainable Energy
	172	4	F		Smart Materials
	174	4	S		Mech. Behavior of Materials
	180	4	F		Materials in Eng. Design
	Choose two of				
PHY	122A/B	4			
	116A	4			
	116B	4			
	at most one of				
EMS	162L	3	W		Structure & Characterization Lab
	170L	3	S		Sustainable Energy Lab
	172L	3	F		Smart Materials Lab
	174L	3	S		Mech. Behavior of Materials Lab

Total Units: 110-112
Example schedule: In most cases, the PHY 9D and ENG 45 requirement is satisfied before the junior year, but an example including these courses is shown. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	40 104A (ENG 45)	45 110A 105A	80 110B+L (9D)
Senior	112+L 115A *EMS 180*	140A 115B 116B	140B 122A *EMS 174*

Table 15: Atmospheric Physics

Concentration Courses:
Units: 37-40 units. *: recommended, #: not offered every year, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	45	4			
GEL	50*	3	FWS		Physical Geology
ATM	60	4	F		Intro. to Atmospheric Sci.
	120	4	F		Atmos. Thermo. and Cloud Physics
	121A	4	W		Atmospheric Dynamics
	121B	4	S		Atmospheric Dynamics
	Choose two of				
	110L	1			
	115L	1			
	112L	1			
	Choose two of				
PHY	122A/B	4			
	116A	4			
	116B	4			
	Choose two of				
PHY	105B	4			
	105C	4	#		Continuum Mechanics
GEL	116N	3	S	GEL 50	Oceanography
	150A	4	S#	GEL 116N,55	Physical and Chemical Oceanography
	150B	3	W	GEL 50	Geological Oceanography
ATM	124	3	F	ATM 60	Meteorological Instruments & Observations
	128	4	W		Radiation and Satellite Meteorology
	158	4			Boundary-Layer Meteorology

Total Units: 110-113
Example schedule: In most cases, the PHY 9D and ENG 45 requirement is satisfied before the junior year, but an example including these courses is shown. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	40 104A ATM 60	45 105A 110A	80 *105B* 110B+L
Senior	ATM 120 112+L 115A *ATM 124*	ATM 121A 140A 115B 116B	ATM 121B 140B 122A

Table 16: Physical Oceanography

Concentration Courses:
Units: 37-40 units. *: recommended, #: not offered every year, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
CHE	2A	5	FW		
PHY	45	4			
GEL	50	3	FWS		Physical Geology
	55	3	F	CHE 2A	Intro. to Geochemistry
	116N	3	S	GEL 50	Oceanography
	150A	4	S#	GEL 116N,55	Physical and Chemical Oceanography
	150B	3	W	GEL 50	Geological Oceanography
	Choose two of				
	110L	1			
	115L	1			
	112L	1			
	Choose two of				
PHY	122A/B	4			
	116A	4			
	116B	4			
	Choose one of				
PHY	105B	4			
	105C	4	#		
GEL	150B	3	W	GEL 50	Geological Oceanography

Total Units: 108-109 **Note:** This degree may not be possible to complete in two years. Students should seek instructor permission to take GEL 150A alongside prerequisites if it is offered in their junior year.

Example schedule: In most cases, the PHY 9D and ENG 45 requirement is satisfied before the junior year, but an example including these courses is shown. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	40 104A CHE 2A (9D)	45 105A 110A GEL 50	80 *105B* 110B+L GEL 159N
Senior	GEL 55 112+L 115A	GEL 150B 140A 115B 116B	GEL 150A 140B 122A

Table 17: Chemical Physics

Concentration Courses:

Units: 36 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
CHE	2A	5	FW		General Chemistry
	2B	5	WS		General Chemistry
	2C	5	FS		General Chemistry
	124A	3	F		Inorganic Chemistry
	110BC*				Physical Chemistry
	128ABC*				Organic Chemistry
	129A*				Organic Chemistry Lab
	210B*				Quantum Chemistry
EMS	147*				Principles of Polymer Materials Science
PHY	45	4			
	115B	4			
	140A	4			
	140B*	4			
	Choose two of				
	110L	1			
	115L	1			
	112L	1			
	Choose one of				
PHY	122A/B	4			
	116A	4			
	116B	4			

Total Units: 109-110

Example schedule: In most cases, the PHY 9D and ENG 45 requirement is satisfied before the junior year, but an example including these courses is shown. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	CHE 2A 40 104A (9D)	CHE 2B 45 110A 105A	CHE 2C 80 110B+L
Senior	112+L 115A CHE 124A	140A 115B 116B	122A

10 Example Course Syllabi

This section contains example syllabi for new courses and existing courses impacted by this proposal. The first paragraph for each course is a brief description suitable for the course catalog, and is generally much less specific than the details that follow. This is to allow some flexibility to adjust the course content purely within the department without contradicting the course catalog.

Instructors are expected to satisfy the brief course description as listed in the course catalog, but are not obligated to follow the detailed example syllabi shown here. However, many of these courses are prerequisite courses, so instructors are expected to consider the impact on downstream courses to their decisions.

The specific computational tools (e.g. Scientific Python, C++) will not be included in the course catalog description. This is to allow the department some flexibility to evolve independently over time. However, the choice of tool set needs to be coordinated throughout the department. It would be extremely disruptive if the instructor for Phy 40 or 45 made changes to the tool set without coordinating with the rest of the department. Specific details about the current computational tool set will be publicly available on the department website, including guidance for installation.

PHY 40 — Introduction to Computational Physics (4): Introduction to programming with examples from numerical analysis and computational physics. Introduction to modern tools used for scientific analysis and computer algebra.

The language for this course will be Python/Anaconda, with some symbolic manipulation via Mathematica or the developing Python equivalent (SymPy). The supported operating systems will be Windows, MacOS, and Linux. The course introduces the Python language and the Scientific Python ecosystem in the context of an introduction to numerical analysis. The major topics of numerical analysis are introduced with the most elementary of algorithms, for example numerical integration via Newton-Cotes methods (e.g. Simpson's rule) are covered, but Gaussian Quadrature methods are not. The Scientific Python tools, which generally implement more sophisticated algorithms, can then be used with a basic understanding of how they work. This approach minimizes formal pedagogy, so that the students can learn by coding themselves. This course has no prerequisites, but most of the elementary techniques are intuitively graphical. For example, Simpson's method of integration can be easily explained as estimating the area under the curve.

There are a surprising large number of excellent textbooks, some dated and many quite recent, in computational physics. These syllabi use Gezerlis for references when possible because the textbook is available as a PDF from the UCD library. Giordano is a particularly excellent source for approachable problems.

The core course content is:

- Python language elements: variables, conditionals, loops, input and output, and lists. Taught through a series of simple math problems: from arithmetic, geometric and Taylor series, to the quadratic equation. (6 hours)

- Scientific Python ecosystem: numpy, matplotlib, scipy including 1-D arrays, plotting, and numerical analysis tools. Taught as encountered.

- Fundamental limits to numerical analysis: representation of numbers on computers, errors from approximation and round-off. (2 hours) [Gezerlis 2]

- Differentiation: Finite difference and error estimation, scipy tools. (2 hours) [Gezerlis 3.3]

- Integration: Newton-Cotes methods, scipy tools (2 hours) [Gezerlis 7.2]
- Roots: bisection, Newton's method, secant method, scipy tools. (2 hours) [Gezerlis 5.2.4-5.2.6]
- Monte Carlo: Quadrature, scipy tools (2 hours) [Gezerlis 7.7.2]
- Ordinary Differential Equations: Euler and Verlet/Leap frog methods, Mass on spring with damping, Euler-Cromer Kepler problem (5 hours) [Gezerlis 8.2, Giordano 4.1]
- Computer Algebra (5 hours): Mathematica or SymPy

The time allocated for core material is generous, which should leave room for topical material. Example topical approachable material:

- Cellular Automata: Game of Life
- Sorting: Bubble sort, Merge Sort, scipy tools
- Chaos: Logistics Map, Period Doubling
- Fractals: Mandelbrot Set
- Fourier Series: visualization for square wave
- Simulating Musical Instruments (Giordano 11)

PHY 45 — Computational Physics (4): Algorithms and programming techniques used in computational physics with examples from introductory physics.

This course will continue to use Python/Anaconda, but will also introduce the C/C++ language. The supported operating systems will be Windows, MacOS, and Linux. The algorithms and problems considered will be more sophisticated than in PHY 40 taking advantage of the fact that students have completed at least PHY 9C/9HD, MAT 21D, and MAT 22A sequences. As some students will be taking MAT 22B concurrently, the more challenging differential equation related material should be left until the second half of the course.

The core material is:

- C/C++ language elements: variables, conditionals, loops, input and output, arrays and pointers. Taught through a series of computing tasks as in 40. (6 hours)
- Continued use of Scientific Python, particularly for plotting and matrices. Some problems will be solved twice: once in Python and once in C++. Taught as encountered.
- Matrices: Linear Algebra, Eigenvalues and Eigenvectors [Gezerlis 4] (3 hours)
- Molecular Dynamics: Direct Simulation [Giordano 9] (2 hours)
- Monte Carlo Techniques: Pseudo-random Numbers, Inverse Transform Sampling, Importance Sampling, Random Walks [Gezerlis 7.7.1-7.7.4, Giordano 7] (3 hours)
- Ordinary Differential Equations: Runge-Kutta, Shooting Method [Gezerlis 8.2-3] (3 hours)
- Partial Differential Equations: Diffusion, Relaxation [Garcia 6,8] (3 hours)

- Fourier Analysis: Spectral methods [Gezerlis 6.4.1-6.4.3, Garcia 8.2] (4 hours)

This leaves plenty of time for topical problems, such as:

- Projectile motion with air resistance [Giordano 2.2] (ODEs)
- Chaos in the Driven Nonlinear Pendulum [Giordano 3.2] (ODEs)
- Extensions to the Kepler problem: precession and Kirkwood gaps [Giordano 4.3, 4.5] (ODEs)
- Charged particle in a magnetic field via Runge Kutta (ODEs)
- Kinetic energy of particle in a box [Gezerlis 3.4] (Differentiation)
- Normal modes of a mass/spring/pendulum system (Matrices)
- Eigenvalues of the Schrodinger equation [Gezerlis 4.5] (Matrices)
- Shooting Method Solution to Schrodinger Equation [Giordano 10.2] (QM / ODE)
- Relaxation Method for solving Laplaces's Equation [Giordano 5.1] (EM / PDEs)
- Manhattan Project, critical mass [Garcia 6.3] (Diffusion / PDEs)
- Direct simulation of an Ideal Gas [Giordano 9] (SM / Molecular Dynamics)

PHY 80 – Experimental Techniques (4): Experimental techniques. Design of circuits. Data analysis, sources of noise, statistical and systematic uncertainties. Light sources, detection, and measurement in basic optical systems.

PHY 80 uses Scientific Python for data analysis. With PHY 40 added as a prerequisite, this component can be more ambitious:

- Plotting and Curve fitting (Current focus)
- Fourier Analysis: discrete sampled data and Shannon-Nyquist, periodogram (New)
- Monte Carlo: generating simulated experimental data. (Expand)
- Machine Learning (Optional)

PHY 104A — Introductory Methods of Mathematical Physics (4): Introduction to the mathematics used in upper division physics courses, including applications of vector spaces, Fourier analysis, partial differential equations.

This course includes review of some material from MAT 21D and MAT 22AB, In particular, instructors teaching 104A should coordinate with the instructor for 110A to ensure that vector calculus is being adequately covered. The amount of time devoted to review can be adjusted in the fall and spring offerings to best suit the class composition, which will be predominantly students from the PHY 9 series, including transfer students, in the fall, versus 9H students in the spring. Textbook: Mathematical Methods in the Physical Sciences, 3rd Edition by Mary L. Boas.

Example coverage:

- Quick Review of Complex Numbers (Ch. 2)
- Quick Review of Sequences and Series, including Taylor (1.1-1.15)
- Quick Review of Linear Transformations (3.6-3.12)
- Review of Vector Calculus (Ch. 6) (as needed)
- Fourier Series (7.1-7.11)
- Fourier Transform (7.12, 13.9)
- Dirac Delta Function (8.11)
- Legendre Series (12.1-12.10)
- Partial Differential Equations (13.2)
- Series Solutions to PDEs (13.3-13.8)
- Calculus of Variations (Chap 9) (if time permits)

PHY 110A — Electricity & Magnetism (4): Theory of electrostatics, magnetostatics, electrodynamics and radiation.

The first quarter of 110 focuses on electrostatics and magnetostatics (Griffiths 1-6). An example schedule:

- Week 1: quick review on vector analysis, Coulombs law, Gausss law, electric potential (2.1,2.2, 2.3)
- Week 2: electric energy, conductors, image method (Cartesian only) (2.4, 2.5, 3.2)
- Week 3: Laplaces equation (Cartesian) (3.1, 3.3.1)
- Week 4: Laplaces equation (spherical only), multipole expansion (3.3.2, 3.4)
- Week 5: dipole in E, polarization, bound charge (4.1, 4.2)
- Week 6: displacement field (4.3)
- Week 7: review of Lorentz force, Bio-Savart, Amperes law (5.1, 5.2, 5.3)

- Week 8: magnetic potential, multipole expansion, dipole in B (5.4, 6.1)
- Week 9: magnetization, bound current, H field (6.1, 6.2, 6.3)

PHY 110B — Electricity & Magnetism (4): Theory of electrostatics, magnetostatics, electrodynamics and radiation.

The second quarter focuses on electrodynamics and radiation (Griffiths 7-12). An example schedule:

- Week 1: motional EFM, Faradays law (7.1, 7.2)
- Week 2: inductance, magnetic energy, Maxwell equations (7.2, 7.3)
- Week 3: conservation laws (8)
- Week 4: plane wave, energy, momentum of a plane wave (9.1, 9.2)
- Week 5: reflection and refraction, absorption and dispersion (only for insulating medium) (9.3, 9.4)
- Week 6: retarded potential formulation (10.1-2)
- Week 7: radiation from dipoles (11.1)
- Week 8: review of Lorentz transformation and relativistic mechanics (12.1, 12.2)
- Week 9: relativistic electrodynamics (12.3)

PHY 110L – Computing Lab for Electricity and Magnetism (1): Applications of computational physics to problems from Electricity and Magnetism.

This course, which has one hour of lecture per week, includes extensive problems from numerical physics related to PHY 110AB, using the techniques introduced in PHY 40 and 45.

- Variations of related problems from PHY 45.
- Visualizing Electric and Magnetic fields (Gezerlis 1.7)
- Multipole Expansion (Gezerlis 4.2)
- Magnetic Fields produced by current distribution (Giordano 5.3-4)
- Waves on a String: Spectral methods (Giordano 6.4)
- Relaxation Method Solution to Laplace's Equation (Giordano 5.1-2, Garcia 8)
- Fourier Analysis: Spectral method (Garcia 8.2)
- Waveguides (Recommended Topic... not covered in 110AB)

PHY 112L – Computing Lab for Statistical Mechanics (1): Applications of computational physics to problems from Statistical Mechanics.

This course, which has one hour of lecture per week, includes extensive problems from numerical physics related to PHY 105A and 112, using the techniques introduced in PHY 40 and 45.

- Variations of related problems from PHY 45.
- Testing the Stefan-Boltzmann Law (Gezerlis 6.6)
- Mean Field Theory Solution to Ising Model (Giordano 8.2)
- Metropolis Algorithm (Giordano 8.3)
- Phase Transitions (Giordano 8.4-8.5)
- Monte Carlo Simulation of Dilute Gas (Giordano 9.1)
- Melting (Giordano 9.2)
- Protein Folding (Giordano 12.1)

PHY 115L — Computing Lab for Quantum Mechanics (1): Applications of computational physics to problems from Classical and Quantum Mechanics.

This course, which has one hour of lecture per week, includes extensive problems from numerical physics related to PHY 115A and 115B, using the techniques introduced in PHY 40 and 45.

- Variations of related problems from PHY 45.
- Symplectic Algorithms
- Extremizing the Action (Gezerlis 5.6)
- Solution of the Time-independent Schrodinger equation: Harmonic oscillator, Lennard Jones potential (Giordano 10.2).
- Variational Quantum Monte Carlo (Giordano 10.4, Gezerlis 7.8)
- Time-dependent Schrodinger equation: reflection of wave packets (Giordano 10.5)
- Spectral method solutions to Schrodinger equation. (Giordano 10.7)
- Matrix Representation of Interacting spin-half particles (Gezerlis 4.5)

PHY 116A — Physics Instrumentation with Analog and Digital Electronics: Experimental and theoretical study of important electronic circuits involving analog and digital components. Feedback, amplifiers, oscillators, noise, integrated circuits, digital logic, timers, analog-to-digital and digital-to-analog converters.

PHY 116B — Physics Instrumentation for Data Acquisition: Experimental application of modern high density integrated circuits. Automated data acquisition, microprocessors, field programmable gate arrays.