Proposal for Revising the Undergraduate Physics Curriculum Version 1.0

Department of Physics

March 28, 2023

1 History and Status of the Proposal

This proposal has been developed over the past three years within the department of physics, led by the undergraduate curriculum committee. The proposal was subjected to an extensive vetting process that involved assigned department readers who were not involved in formulating the initial plan. The proposal was unamimously supported by the department in a vote held in December 2021.

The impact of the proposal outside of the department of physics is expected to be minimal. The proposal leaves PHY 7 and 9 unchanged, apart from a long overdue clean up of the mathematics prerequisites, which make them consistent with the equivalencies accepted by the department of mathematics, and increases the options available to students. The proposal does eliminate PHY 9HE, but a search of the current course catalog does not indicate any majors that explicitly list PHY 9HE as a requirement (even an alternate) or prerequisite.

2 Objectives of the Proposal

An example schedule of student coursework 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 for BS Physics majors 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.

Table 1: An example schedule satisfying the *current requirements* 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.

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(3) *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 satisfying the *current requirements* for an undergraduate physics major that transfers to UC Davis in their junior year and takes 122A. Most of our incoming transfer students have not taken an equivalent course for at least one of PHY 9D, 40, or 80. This example considers the extreme case where they have completed none of these courses upon arrival in the junior year. 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.

Year	Fall	Winter	Spring
Junior	9D(4) 104A(4) 105A(4) 102(1)	105B(4) 110A(4) *80(4)*	40(3) 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)*

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 that course does not contain any content which is a prerequisite for upper division class 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 coursework, and 80 is not taken by all students. The result of this stalling is that the junior and senior years are a race to complete the degree requirements, leaving very little flexibility or time for advanced electives.

- Students that transfer to UC Davis for their junior year face a wall of coursework that they have to handle in the first quarter: math methods, mechanics, and modern physics. Many also take 102, which instructors have found challenging to teach within the workload limits of a one-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 coursework. 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 coursework 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. The math prerequisites for lower division coursework are broken out separately in Table 5. Example schedules are presented in Tables 6-8.

A primary feature of this proposal is that incoming transfer students now overlap in some courses with sophomores who 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 who took the honors sequence also provides tremendous additional flexibility to their schedule. The example schedule in Table 6 assumes the student takes each class nearly as soon as possible, leaving ample time in their senior year for additional electives.

Transfer students who 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 8; 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 coursework in any quarter.

The college imposes a limit of 110 units of required coursework, 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 appropriately sized four-unit PHY 45 course. Also, the major stress point for transfer students is in their first quarter, which this proposal substantially improves. The proposal also adds significantly more schedule flexibility, which should also help alleviate pressure.

Table 3: Preparatory Subject Matter

Units: 52-54. *: recommended.
See Table 5 for math prerequisites.

Course		Units	Offered	Prereqs	Name
MAT	21A	4	FWS		Differential Calculus
	21B	4	FWS		Integral Calculus
	21C	4	FWS		Partial Derivatives and Series
	21D	4	FWS		Vector Analysis
	one of:				
MAT	22A	3	FWS		Linear Algebra
	27A	3	FWS		Linear Algebra
	67	4	FWS		Mod. Linear Algebra
MAT	22B	3	FWS		Differential Equations
	or				
MAT	27B	3	FWS		Differential Equations
PHY	9A	5	FS		Class. Physics *(Class. Mech.)*
	9B	5	FW	9A/9HA	Class. Physics *(Waves, Thermo, Optics)*
	9C	5	WS	9B	Class. Physics *(Elec. and Magn.)*
	9D	4	FS	9C	Mod. Physics *(Rel. and QM)*
	or				
PHY	9HA	5	F		Honors Physics *(Class. Mech.)*
	9HB	5	W	9A/9HA	Honors Physics *(Rel. and Stat. Mech.)*
	9HC	5	S	9HB	Honors Physics *(Waves and QM)*
	9HD	5	F	9HC	Honors Physics *(Elec. and Magn.)*
PHY	40	3	F		Introduction to Physics Computation
	45	4	W	40,9C/9HD	Computational Physics
	80	4	FS	9C/9HD,40	Experimental Techniques
	185*	1	S		Careers in Physics
	190*	1	F		Careers in Physics

Table 4: Depth Subject Matter

Units: 39-43. *: recommended, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	104A	4	FS	9C/9HD,MAT 22B	Mathematical Physics
	105A	4	W	9C/9HD, MAT 22A, ‖22B	Classical Mechanics I
	105B	4	S	105A,40†	Classical Mechanics II
	110A	4	W	104A,9C/9HD	Electricity and Magnetism I
	110B	4	S	110A	Electricity and Magnetism II
	110L	1	S	45/ECS 36B, ‖110B	Comp. Lab in Electricity and Magn.
	112	4	F	104A,9D/9HD	Thermo. and Stat. Mech.
	112L	1	F	45/ECS 36B, ‖112/CHE 110A	Comp. Lab in Statistical Mechanics
	115A	4	F	104A,105A,9D/9HD	Quantum Mechanics I
	115B	4	W	115A	Quantum Mechanics II
	115L	1	W	115A/CHE 110C,‖115B* 45/ECS 36B	Comp. Lab in Quantum Mechanics
	115C*	4	S	115B,45/ECS 36B	Appl. of Quantum Mechanics
PHY	117	4	F	80	Phys. Instr. with A&D Electronics.
	118	4	W	80,45/ECS 36B	Phys. Instr. for Data Acquisition.
	or				
PHY	122A/B	4	WS	80,104A,105A,110B & ‖112 ‖115A	Advanced Physics Laboratory

†: Instructor permission may be obtained to take PHY 105B without the PHY 40 prerequisite.
Electives: Additional electives to bring the total number of 3 or more unit upper division courses to 14, including at least three from capstone courses. (4-5 courses, totaling 15-20 units with current offerings) Includes at most one from PHY 194H series, 195, 198, or 199 and excludes PHY 160.
Total Units: 110-113

Table 5: Math prerequisite for lower division courses related to this proposal. Where indicated, course grades are the minimum accepted to meet prerequisites. The prerequisites for the math courses are set by the math department and are only reported here. Where possible, math prerequisites for physics courses adopt the same choices made by the math department with respect to equivalent math coursework.

Course		Math Prereqs (Minimum Grade)	Name
MAT	16A		Short Calc.
	16B	21A/21AH/17A/16A(C-)	Short Calc.
	16C	21B/21BH/17B/16B(C-)	Short Calc.
	17A		Calc (Bio&Med)
	17B	21A/21AH/17A/16A(C-)	Calc (Bio&Med)
	17C	17B(C-)	Calc (Bio&Med)
	21A		Calculus
	21B	21B/21BH(C-) or 17A(B)	Calculus
	21C	21B/21BH/17C/16C(C-) or 17B(B)	Calculus
	21D	21C/21CH(C-) or 17C(B)	Calculus
	22A	21C/21CH/17C/16C(C-)	Linear Algebra
	22B	67/22A(C-)	Diff. Eqs.
	67	21C/21CH(C-)	Mod. Lin. Alg.
PHY	9A	21B/21BH/17C/16C(C-) or 17B(B)	Class. Physics
	9B	21C/21CH(C-) or 17C(B)	Class. Physics
	9C	21D(C-)	Class. Physics
	9D	22A(C-) or 67(C-)	Class. Physics
		‖22B	
PHY	9HA	‖21B/‖21BH	Hon. Physics
	9HB	21B/21BH(C-)	Hon. Physics
	9HC	21C/21CH	Hon. Physics
	9HD	21D	Hon. Physics
PHY	45	‖22B	Computational Physics

Table 6: An example schedule satisfying the *proposed requirements* 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(3)	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)*

Table 7: An example schedule satisfying the *proposed requirements* 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(3)	*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 8: An example schedule satisfying the *proposed requirements* 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)	105A(4)	105B(4)
	40(3)	110A(4)	110B+L(5)
	104A(4)	45(4)	*80(4)*
Senior	115A(4)	115B+L(5)	*115C(4)*
	112+L(5)	*122A(4)*	*CAP(4)*
	X(3-4)	*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 unchanged, but their prerequisites have been adjusted for consistency with the math prerequisites (including minimum grades) used by the math department and to match existing policy (e.g. 9A is acceptable prerequisite for 9HB.)
- 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. Most four-year students from honors physics will take the spring offering, whereas most incoming junior year transfer students will take the fall offering. This will allow the course to be pitched slightly differently in each quarter, 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 coursework 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, relativistic mechanics, and introductory electricity and magnetism. This material must be covered adequately in the 9 series and 104A.

- 112: The 115A prerequisite for 112 has been removed, and the treatment must rely on quantum from the PHY 9 series instead. Fermi and Bose statistics will be introduced independently in 112. PHY 9 and 9H must consistently cover discrete energy levels from the particle in a box and simple harmonic oscillator. The annual faculty curriculum discussion is the mechanism for ensuring this is so.

- 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). As this is an elective course, there is no need to implement it immediately, and it can be developed first as a PHY 150 course.

- The computational courses are described in Section 5. PHY 40 is updated, PHY 102 and 104B are dropped, and new courses PHY 45, 110L, 112L and 115L are added.

- The traditional lab courses are discussed in Section 6. PHY 80, 116A, 116B, and 116C are replaced with PHY 80, 117, and 118. PHY 122A/B is unchanged.

Example syllabi for all courses impacted by this proposal are presented in Section 11.

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.) Instructors teaching a one-unit computation lab course will receive credit for one third of a standard podium course. The three new computational lab courses together add one new instructor. The second offering of 104A and the new required course 45 add two new instructors. But dropping courses 9HE, 102, 104B, 110C and replacing 116ABC with 117 and 118 frees 4.3 instructors, for a net decrease of 1.3 instructors. If the need for more sections of 80 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 Theoretical Physics

At the core of any undergraduate physics degree are the following topics in theoretical physics:

- Classical Mechanics (105AB): the fundamental principles of physical laws (e.g. least action and symmetries) are taught in a familiar and intuitive context.

- Electromagnetism (110AB): a remarkable special case of classical phenomena that anticipate non-Newtonian physics (e.g. special relativity, gauge theories). No other force in nature can be understood so completely in such a straightforward fashion.

- Quantum Mechanics (115AB): the rules governing the microscopic world are different from those governing our familiar macroscopic world. The rules are not intuitive but they can be codified and used to make quantitative predictions which can be experimentally verified.

- Statistical Mechanics (112): the crucial statistical explanation for how microscopic laws ultimately produce the macroscopic world which we inhabit.

The physics department has recently adopted a procedure for maintaining example syllabi for core courses, through an annual faculty meeting discussion and vote. This is the mechanism for ensuring that prerequisite material is being appropriately and consistently covered in the proper courses. The example syllabi, as presented during the first annual faculty curriculum discussion are presented in Section 11. This proposal need not resolve all of the issues brought up in these discussions, as these discussions will continue, with an update and faculty vote as needed.

The major topics from the first curriculum discussion were:

- It was agreed that 105A needs to cover Hamiltonian mechanics, by adding supplementary material to the preferred textbook (Morin).
- The treatment of radiation in 110AB is limited.
- There is support for covering waveguides in either 110AB, 80, or even 110L.
- PHY 104A plays a central role in providing students with the analytic techniques needed for upper division coursework. This course has been far too topical for the central role it plays in our program, and the example syllabi should be closely followed by future instructors.
- The 115AB content is presented as either the historical progression or spin first. The instructors will coordinate each year and agree on an approach. Sufficient review is included in both versions PHY 115B so that students who took 115A under a different progression do not miss any crucial material, such as particle-in-a-box, simple-harmonic oscillator, or angular momentum.

5 Computational Physics

One of the major objectives of this proposal is to better integrate computational physics throughout the curriculum. To do so, students must master 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 Jupyter 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 2018, we added a new required course, PHY 40, which introduces programming with both C++ and python. This format leaves no time for symbolic computation and little time for exploring additional features of Scientific Python beyond the basic Python language. In 2021, the course was taught exclusively with Scientific Python, which was found to be much more workable. However, even with this reduced scope, most students taking the course are not yet ready to do extensive unsupervised computational work, and only manage to make significant progress during lab sections with TA support. For this reason, recent instructors agree that a three unit course, with essentially no homework, is a more appropriate format for PHY 40.

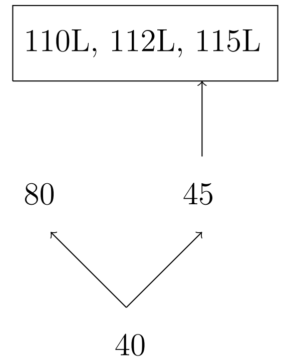

Figure 1: Prerequisite structure of computational courses.

In the current program, the additional computational physics requirement is either PHY 102 (1 unit) or 104B (4 units). This proposal replaces these options with a single new required four-unit computational physics course, PHY 45. In addition, BS physics majors are required to take three one-unit computational lab courses: 110L,112L, and 115L. PHY 80 is a traditional lab course, as described in Section 6, but it is included in this discussion as it also includes significant computational aspect.

The computational physics content of the required courses in this proposal include:

- 40: This three-unit course has no prerequisites and assumes no prior knowledge of programing. It provides an introduction to programming using examples from computational physics. It includes 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. 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: This traditional lab course includes extensive use of scientific python for data analysis and presentation, including curve fitting and plotting scientific data.

- 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. One unit courses should involve three hours of academic work per week as described below. Each course is offered in a different quarter, so students get three units of computational problem-solving spread across at least one year. BS physics majors are required to take all three. A major emphasis of these lab courses is to give students practice at using programming to solve computational physics problems *independently*. They will be solving problems as homework, instead of in a lab section with TA support.

- 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 (22 recommended) of coursework 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. All majors now require PHY 40, so that could be added as a prerequisite to any upper division course. All applied majors include 45 or an equivalent, so, for example, 140A or 140B could include a computational component.

The content of PHY 40, 45, 105L, 110L. and 115L will likely evolve with our experience teaching these courses. Furthermore, the content of the one-unit computational labs will benefit from coordination with the lecturer for the corresponding lecture course (e.g. 115L and 115B). The annual faculty curriculum discussion will be one venue for these discussions to unfold.

One-unit workload: It is important that 110L, 112L, and 115L are taught as one-unit courses. A one-unit course should involve three hours of total academic work per week, which in this case includes the one hour of scheduled lecture time. For example, an appropriate workload would be five computing assignments due every two weeks during the ten week quarter. Each assignment would be introduced with a one-hour lecture, with a second one-hour lecture devoted to helping students complete the assignment. The assignments should take about five hours to complete, including one hour of help.

6 Experimental Physics

In traditional lab courses, students conduct scientific experiments, gain crucial hands on experience, and see theoretical concepts from a new perspective. The unit cap on required coursework places extreme time pressure on these essential lab experiences. In the current program, BS physics majors are only required to take four units of upper division traditional lab work, although many opt to take more.

Table 9: Content of New Lab Courses

Course	Replaces from	Content
80	116A	Passive Analog Electronics
	116C	Data Analysis
117	116A	Active Analog Electronics
	116B	Elementary Digital Electronics
118	116B	FPGAs
	116C	CPUs

PHY 80 was introduced in 2018, and is currently a prerequisite for 122A/B. It was anticipated that this would relieve some of the intense time pressure in these courses. The disruption from remote teaching during 2020 and 2021 has limited our ability to assess the effectiveness of this change, but preliminary indications were that incoming PHY 122A/B students were indeed better prepared.

In the current program, much of the content in PHY 80 is reproduced in the 116ABC sequence. PHY 116A covers passive analog electronics and basic lab equipment, and 116C covers data analysis including experimental uncertainties and curve fitting. Some students take PHY 80 before starting the PHY 116ABC sequence, while others do not. In this proposal, the three quarter 116ABC

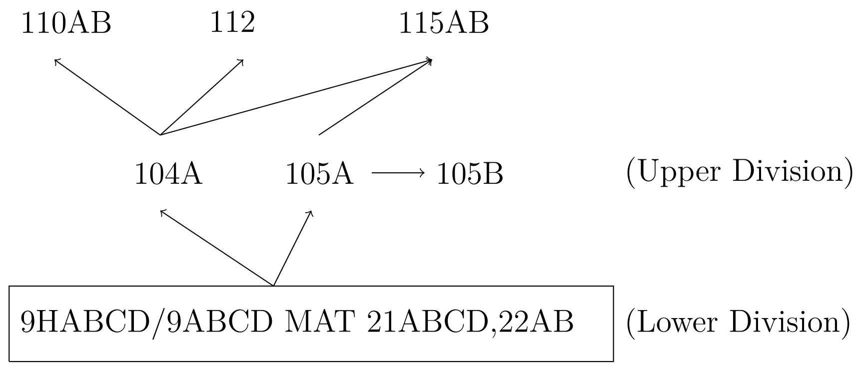

Figure 2: The prerequisite structure of required non-elective theoretical physics and math courses of the physics BS major. Internal prerequisite structure of lower division coursework is not shown. For clarity, only the most advanced prerequisites for each course are indicated.

sequence is replaced with two new courses: 117, which covers analog and digital electronics, and 118, which covers data acquisition with microprocessors and FPGAs. Both courses have PHY 80 as a prerequisite. No content is lost in this remapping, which is summarized in Table 9

The 122A/B labs cycle students through experimental stations, and enrollment in each quarter is limited by the number of available stations. This proposal makes some adjustments to the prerequisites of 122A/B which would allow for fall offerings. This will help meet the expected increase in demand for 122A/B due to increased enrollment. As can be seen in Table 6, many seniors have room to take 122A/B in the fall of their senior year. We also plan to add additional stations to 122A/B, which is independent from this proposal.

PHY 80, 117, and 118 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 117 and 118 will be offered in fall and winter respectively. The department plans to expand the lab space available for 80, 117, and 118 to meet the needs of increased enrollment.

7 Prerequisites

An overview of the prerequisite structure of the core theoretical physics courses is shown in Fig. 2. PHY 104A is the major bottleneck in our program, as it requires the most advanced material from the first tier (MAT 22B) but is required for every course in the upper tier. 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.

The most important changes to the prerequisite structure in the proposal are:

- The 9 and 9H prerequisites have been updated to better reflect the current policy actually enforced.
- PHY 112 does not require 115A anymore, it is taught at a level where 104A and PHY 9A-D suffice.

- PHY 110A does not require 105A anymore.
- PHY 105B requires 40, so that computational examples can be used in this course if the instructor chooses.
- PHY 80 adds 40 as a prerequisite.
- PHY 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, although that will never happen unless we add a fall offering of 122A/B.
- The 116ABC sequence is replaced with independent courses 117 and 118 which each have 80 as a prerequisite.

The new prerequisite structure is considerably more flexible. In the junior year of Tables 7 and 8 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 6 is even more forgiving.

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 winter 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 preclude 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 10 and 11. To avoid version conflicts, some information in Tables 3 and 4 is not duplicated in these tables. Example schedules are presented in Table 12.

Table 10: Preparatory Subject Matter: Astrophysics, Applied Physics, and AB.

Units: 48-50. *: recommended.

Course		Units
MAT	21A	4
	21B	4
	21C	4
	21D	4
	one of:	
MAT	22A	3
	27A	3
	67	4
MAT	22B	3
	or:	
MAT	27B	3
PHY	9A	5
	9B	5
	9C	5
	9D	4
	or	
PHY	9HA	5
	9HB	5
	9HC	5
	9HD	5
PHY	40	3
	80	4
	185*	1
	190*	1

Table 11: Depth Subject Matter: Astrophysics

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

Course		Units	Offered	Prereqs	Name
AST	25*	4			
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			
	117	4			
	118	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
	198	3+			Directed Group Study
	199	3+			Special Study for Adv. Undergrads.

PHY 108 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: 108-114

Table 12: 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 104A 151$^{\#}$ (9D)	105A 110A 153$^{\#}$	80 110B *105B/150*
Senior	115A 152$^{\#}$ 112	115B 156$^{\#}$ *130A/155/GEL 163*	108+L 157/122A/B *158$^{\#}$/129A/130B*

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

9 Proposed Applied Physics Majors

The applied physics majors overlap significantly with the physics major, and so most of the updates already proposed apply directly to the applied physics majors. In this proposal, all applied physics majors now require PHY 40, 45 (or an equivalent), 80, and at least one computing lab (from 110L,112L, and 115L). Most require two upper division lab courses (from 122A/B, 117, 118) except where noted.

The applied physics majors typically require significant upper division coursework outside of the physics department. This proposals makes several adjustments to the applied physics major requirements which remove required courses that are no longer offered regularly, or include a prohibitively large number of prerequisites. The proposed requirements take advantage of new relevant course offerings, by giving students more options to choose from, offering greater flexibility.

The applied physics majors (excluding chemical physics) require the preparatory courses in Table 10 and the depth courses listed in Table 13. Together, these required courses account for 72-74 units, leaving 38 units for concentration courses as detailed in the following tables. This proposal includes modifications to all of the applied physics majors:

- The Computational Physics major does not require PHY 45 and ECS 36B will satisfy the prerequisite for the computing labs. The elective choices from the Computer Science and Engineering department have been extended. See Table 14.
- The Physical Electronics major does not include 117 and 118 as part of the upper division lab requirement, only 122A/B is required. The major instead includes a large amount of electronics from the Electrical and Computer Engineering department. Due to unit limits, only one computational lab is required. See Table 15. An example schedule is presented in Table 16.
- The Materials Science major is renamed Materials Physics, and the elective choices have been extended. Students may now use a Material Science and Engineering lab course as one of their required upper division lab courses. See Table 17.
- 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 18.
- 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. See Table 19. Additional example schedules are provided in Tables 20-22.
- The Chemical Physics major requires the courses listed in Tables 10 and 23. An example schedule is presented in Table 24. Both chemistry and physics have significant lower division coursework as prerequisite for upper division coursework. The additional 15 units of lower division general chemistry course work required by this major limits the number of upper division courses that can be required. This major features two paths, one featuring PHY 112, 115AB, 140AB and the other featuring CHE 110ABC 128AB. The latter choice relies on

the treatment of quantum mechanics and thermodynamics provided by our colleagues in the chemistry department. This major requires 6 units of upper division lab work in chemistry or physics.

Some of the majors might benefit from further revisions, which we plan to pursue once we have experience with the significant changes already proposed here. For example, it would be helpful if PHY 115AB were listed as an alternative prerequisite for CHE 110B.

Table 13: Depth subject matter for all applied physics majors excluding chemical physics.

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

Table 14: Computational Physics

Additional Preparatory Courses:
Units: 12 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

Concentration Courses:
Units: 18 units. *: recommended, #: not offered every year, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
ECS	122A	4	FWS		Algorithm Design & Analysis
	Choose two of				
PHY	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			
	117	4			
	118	4			

Additional Electives: (8 units) Two courses for a total of at least 8 units of additional upper division coursework from ECS, MAT, or PHY.
Total Units: 110-112

Example schedule: 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+L 115A	*ECS 122B* *118*	*122A*

Table 15: Physical Electronics

Additional Preparatory Courses:
Units: 8 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
ENG	17	4	FWS		Circuits I
PHY	45	4			

Concentration Courses:
Units: 30 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
EEC	100	4	FW		Circuits II
PHY	115B*	4			
	140A	4			
	140B*	4			
	122A/B	4			
	Choose two of				
PHY	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: 110-112

Table 16: Example two-year schedule for Physical Electronics major: In most cases, the PHY 9D and ENG 17 requirements are satisfied before the junior year, but the first example shows how those courses can be accommodated. 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+L 115A *EEC 140A*	140A *EEC 110A* *EEC 150A*	122A/B *EEC 110B* *EEC 245/249*

Table 17: Materials Physics

Additional Preparatory Courses:
Units: 8 units. *: recommended, #: not offered every year, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	45	4			
ENG	45	4	FWS		Properties of Materials

Concentration Courses:
Units: 30-34 units. *: recommended, #: not offered every year, ‖: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	115B	4			
	140A	4			
	140B	4			
	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			
	117	4			
	118	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: 110-116

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+L 118	140B 122A *EMS 174*

Table 18: Atmospheric Physics

Additional Preparatory Courses:
Units: 11 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.

Concentration Courses:
Units: 27-29 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
ATM	120	4	F		Atmos. Thermo. and Cloud Physics
	121A	4	W		Atmospheric Dynamics
	121B	4	S		Atmospheric Dynamics
	Choose one of				
PHY	110L	1			
	115L	1			
	112L	1			
	Choose two of				
PHY	122A/B	4			
	117	4			
	118	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	ATM 60	Radiation and Satellite Meteorology
	158	4	S	ATM 121A	Boundary-Layer Meteorology

Total Units: 110-114

Example schedule: In most cases, the PHY 9D and GEL 50 are taken 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 (9D)	45 105A 110A (GEL 50)	80 *105B* 110B
Senior	ATM 120 112+L 115A	ATM 121A 118	ATM 121B 122A *ATM 128*

Table 19: Physical Oceanography

Additional Preparatory Courses:
Units: 15 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
ATM	60*	4	F		Intro. to Atmospheric Sci.

Concentration Courses:
Units: 23-25 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
GEL	116N	3	S	GEL 50	Oceanography
	150A	4	S#	GEL 116N,55	Physical and Chemical Oceanography
	Choose two of				
PHY	110L	1			
	112L	1			
	115L	1			
	Choose two of				
PHY	122A/B	4			
	117	4			
	118	4			
	Choose two of				
PHY	105B	4			
	105C	4	S#		Continuum Mechanics
ATM	115	3	S	ATM 60	Hydroclimatology
	116	3	F		Modern Climate Change
	120	4	F	ATM 60||	Atmos. Thermo. and Cloud Physics
GEL	150B	3	W	GEL 50	Geological Oceanography

Total Units: 110-114
Note: For transfer students arriving in their junior year, this degree may not be possible to complete in two years. Students should seek instructor permission to take GEL 150A alongside 116N prerequisite if it is offered in their junior year.

Table 20: Example two-year schedule for Physical Oceanography major. In most cases, the PHY 9D, CHE 2A, and GEL 50 requirements will be 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 110B+L GEL 116N
Senior	GEL 55 112+L 115A	*GEL 150B* *118*	GEL 150A *122A*

Table 21: Example two-year schedule for Physical Oceanography major: This schedule assumes student took CHE 2A, GEL 50, and PHY 9D before the Junior year, and student receives instructor permission to take GEL 150A concurrently with GEL 116N. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives.

Year	Fall	Winter	Spring
Junior	40 104A GEL 55	45 105A 110A	110B GEL 116N GEL 150A
Senior	80 112+L 115A	*118* *GEL 150B*	*122A*

Table 22: Example four-year schedule for Physical Oceanography major. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives. If GEL 150A is not offered in junior year, it can be taken in senior year.

Year	Fall	Winter	Spring
Freshman	MAT 21A CHE 2A	MAT 21B GEL 50	MAT 21C 9A
Sophomore	MAT 21D 9B GEL 55	MAT 22A 9C	MAT 22B 9D GEL 116N
Junior	40 104A	45 110A 105A	80 110B+L GEL 150A
Senior	115A 112+L	*118* *GEL 150B*	*122A*

Table 23: Chemical Physics

Additional Preparatory Courses:

Units: 19 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
PHY	45	4			

Concentration Courses:

Units: 43-45 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	104A	4			
	105A	4			
	110A	4			
	110B	4			
CHE	124A	3			Inorganic Chemistry
PHY	115A	4			
	115B	4			
	112	4			
	140A	4			
	140B*	4			
	Or:				
CHE	110A	4			Physical Chemistry: Intro to QM
	110B	4			Physical Chemistry: Atoms and Molecules
	110C	4			Physical Chemistry: Thermodynamics
	128A	4			
	128B*	4			
PHY	115A*	4			
	112*	4			
	Choose two of:				
PHY	110L	1			
	112L	1			
	115L	1			
	6 or more units:				
PHY	122A/B	4			
	117	4			
	118	4			
CHE	105	4			Analytical & Physical Chemical Methods
	115	4			Instrumental Analysis
	124L	2			Laboratory Methods in Inorganic Chemistry
	129A	2			Organic Chemistry Laboratory
	129B	2			Organic Chemistry Laboratory
	129C	2			Organic Chemistry Laboratory

Total Units: 110-114

Table 24: Example two-year schedule for the chemical physics major. Physics course numbers are shown unless otherwise indicated. Courses in italics are electives. In most cases, the PHY 9D and CHE 2 requirements are satisfied before the junior year, but an example including these courses is shown.

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 118	140B 122A

Table 25: Geological Physics

Additional Preparatory Courses:
Units: 13 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
PHY	45	4			
GEL	50	3	FWS		Physical Geology
	50L	2			Physical Geology Laboratory
ATM	60	4	F		Intro. to Atmospheric Sci.

Concentration Courses:
Units: 25-30 units. *: recommended, #: not offered every year, ||: concurrently.

Course		Units	Offered	Prereqs	Name
	Choose two of				
PHY	110L	1			
	115L	1			
	112L	1			
	Choose two of				
PHY	122A/B	4			
	117	4			
	118	4			
	Choose five of				
PHY	105B	4			
	105C	4			Continuum Mechanics
ATM	120	4	F	ATM 60	Atmospheric Thermodynamics & Cloud Physi
	121A	4	F	ATM 120	Atmospheric Dynamics
	121B	4	W	ATM 121A	Atmospheric Dynamics
GEL	116N	3			Oceanography
	146	3			Radiogenic Isotope Geochemistry & Cosmoche
	150A	4	S#	GEL 116N,55	Physical and Chemical Oceanography
	150B	3	W	GEL 50	Geological Oceanography
	incl at least two:				
GEL	161	3	S#	GEL 50	Geophysical Field Methods
	162	3	W#	GEL 50	Geophysics of the Solid Earth
	163	3	F#	GEL 50	Planetary Geology

Total Units: 110-117

Example schedule: In most cases, the PHY 9D and GEL 50 are taken 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 (9D)	45 105A 110A (GEL 50+L)	80 105B 110B GEL 161
Senior	112+L 115A ATM 120	ATM 121A 118 GEL 162	122A

10 Proposed AB Physics Major

The proposed requirements for the AB Physics major are listed in Tables 10 and 26. To avoid version conflicts, some information in Tables 3 and 4 is not duplicated in these tables.

The college requirements for an AB degree include a cap of 80 units, of which at least 36 must be upper division. This presents a very fine needle to thread indeed! The current AB Physics degree requires 82 units, which was approved by the Education Policy Committee in the past despite exceeding the cap. This proposal requires only 80 units for the AB.

The proposed AB Physics major only requires 32 units of upper division coursework, which does not reach the required 36 unit minimum. However, several required lower-division courses, such as PHY 80 and PHY 45 include significant prerequisites and are therefore quite nearly upper division courses. We will therefore ask for an exception to the 36 unit **minimum** (our preference) or an exception to the 80 unit **maximum** (and require two instead of one elective upper division courses in Table 26).

Table 26: Depth Subject Matter

Units: 32. *: recommended, ‖: concurrently.

Course		Units
PHY	104A	4
	105A	4
	110A	4
	110B	4
	112	4
	115A	4
PHY	122A/B	4
	At least one of	
PHY	129A	4
	130A	4
	140A	4
	151	4
	152	4
	153	4
	156	4
	158	4

Foreign Language: The AB degree requires proficiency in a language other than English (15 units)
Total Units: 80-82 units, excluding language requirement.

11 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 maintain the course content 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 obliged to follow the detailed example syllabi shown here. However, many of these courses are prerequisite courses, so instructors are expected to consider how their course content decisions will impact downstream courses.

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 (3): 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. Whenever possible, special cases with analytic solutions are used to validate the numerical approach.

We find that students taking this as their first computing course are not yet ready to complete computing exercises unsupervised. Therefore, this course has nearly zero homework outside of the schedule lecture and lab time.

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
- Analytic solutions to special cases are calculated and used throughout the course to validate the numerical approach.

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 of computational physics with applications from introductory physics.

This course builds on the programming, numerical analysis, and basic computational physics techniques from PHY 40. The algorithms and problems considered in this course are more sophisticated, using theoretical physics and mathematical concepts from PHY 9ABC, and MAT 21ABCD, and MAT 22A. Students may take MAT 22B concurrently, so the more challenging differential equation related material is left for 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 Schrödinger equation [Gezerlis 4.5] (Matrices)
- Shooting Method Solution to Schrödinger Equation [Giordano 10.2] (QM / ODE)
- Relaxation Method for solving Laplace'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)
- Analytic solutions to special cases are calculated and used throughout the course to validate the numerical approach.

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 — Introduction to Mathematical Methods in Physics (4): Introduction to the mathematics used in upper division physics courses. Vector spaces, Fourier analysis, and 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. It might be beneficial to leave vector analysis until the end of course, as many students will start 110A in the following quarter. Note that treatment of Fourier Transforms is restricted to the limit of the Fourier Series as the period becomes infinite.

Example coverage:

- Quick Review of Complex Numbers (Ch. 2) (as needed - 1.5 hour)
- Quick Review of Sequences and Series, including Taylor (1.1-1.15) (as needed - 1.5 hour)
- Linear Algebra (3.6-3.12,3.14,12.6) (6 hours)
- Fourier Series and Transforms (7.1-7.12) (6 hours)
- Dirac Delta Function (8.11) (1.5 hours)
- Legendre Series (12.1-12.10) (3 hours)
- Partial Differential Equations (Intro+13.2) (3 hours)
- Series Solutions to PDEs (13.3-13.8) (3 hours)
- Review of Vector Calculus (Ch. 6) (important for 110A - 3 hours)
- Linearity and Dimensional Analysis (reinforced throughout course)

PHY 104B — Intermediate Methods of Mathematical Physics (4): Continuation of 104A. Contour Integration, Fourier Transforms, and other topics in Mathematical Physics.

This is more topical than PHY 104A, but some topics should be routinely covered:

- Contour Integration (Ch. 14)
- Fourier Transforms

while others are at the discretion of the instructor:

- Tensors (Ch. 10)
- Group Theory
- Green Functions
- Probability and Statistics (Ch. 15)

PHY 105A — Classical Mechanics I (4): Principles and applications of Newtonian mechanics. Introduction to Lagrangian and Hamiltonian mechanics.

The recommended textbook for this course is Morin plus supplementary material to include Hamiltonian dynamics. Hamiltonian dynamics must be covered reliably in this course. It cannot be postponed until PHY 105B, as not all students will take 105B before taking quantum mechanics.

- Basic Problem Solving Techniques (Ch. 1) (reinforce throughout)
- Newtonian Mechanics (Ch. 2-3) (2 weeks)
- Oscillations (Ch 4) (1.5 weeks)
- Conservation of Energy and Momentum (Ch 4)(1.5 weeks)
- Lagrangian Mechanics (1.5 week)
- Hamiltonian Mechanics (1.5 week)

PHY 105B — Classical Mechanics II (4): Continuation of PHY 105A. Lagrangian and Hamiltonian Mechanics, Calculus of Variations, Conservation Laws, Non-inertial Frames, Special Relativity.

This course goes beyond the material in Morin. Reference text is Marion and Thorton. The core material which must be reliably covered is:

- Review of Calculus of Variations, Lagrangian and Hamiltonian Mechanics (Ch 6-7)
- Gravity, Central Force Motion and Angular Momentum (Ch 5, 8)
- Non-inertial Frames (Ch 10)
- Special Relativity (Ch 14)

That leaves time for additional topical material, for example:

- Dynamics of a System of Particles, Collisions (Ch 9)
- Rigid Body Dynamics (Ch 11)
- Continuous Systems and Waves (Ch 13)

PHY 110A — Electricity and Magnetism I (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, Coulomb's law, Gauss's 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: Laplace's equation (Cartesian) (3.1, 3.3.1)
- Week 4: Laplace's 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, Ampere's 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 and Magnetism II (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, Faraday's 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)

This version omits wave guides (9.5) and radiation from point charges (11.2). These topics could be included by spending less time on other topics.

PHY 110L — Computational Physics 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.

See comments in Section 5 regarding workload for one unit courses. Example topics for assignments include:

- 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
- Analytic solutions to special cases are calculated and used throughout the course to validate the numerical approach.

PHY 112 — Thermodynamics and Statistical Mechanics (4): Introduction to classical and quantum statistical mechanics and their connections with thermodynamics.

The reference text is "Thermal Physics" by Schroeder. The core topics are:

- Energy in Thermal Physics (Chap 1)
- Second Law of Thermodynamics (Chap 2)
- Interactions and Implications (Chap 3)
- Free Energy (Chap 5)
- Boltzmann Statistics (Chap 6) (Target for midpoint of course)
- Quantum Statistics (Chap 7)

PHY 112L — Computational Physics 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.

See comments in Section 5 regarding workload for one unit courses. Example topics for assignments include:

- 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)
- Analytic solutions to special cases are calculated and used throughout the course to validate the numerical approach.

PHY 115A — Quantum Mechanics I (4): Introduction to quantum mechanics. The Schrödinger Equation, Hilbert Space, Dirac Notation, position and momentum space representations, stationary states, and applications.

The topics in this course (and PHY 115B) may be presented as a historical progression or with spin first. Both approaches are valid but must be coordinated between both courses. The reference text for spin first is Townsend, and the reference for historical progression is Griffith. Either ordering provide a sufficient introduction to quantum mechanics by the end of PHY 115A for majors that do not require PHY 115B.

The core material for the Griffith-based progression is:

- Wave functions and the Schrödinger equation (1.1-1.4) (2 hours)
- Momentum, operators, uncertainty principle (1.5-1.6) (2 hours)
- Stationary states, infinite square well (2.1-2.2) (4 hours)
- Harmonic oscillator (2.3) (4 hours)
- Free particle, momentum space; delta function potential (2.4) (3 hours)
- Finite square wells; the scattering matrix (2.5-2.6) (3 hours)
- The WKB approximation (9.1-9.2) (2 hours)
- Linear algebra, Hilbert spaces, operators (3.1-3.3) (2 hours)
- Dirac notation, Axioms of quantum mechanics, Uncertainty (3.4-3.6) (2 hours)

This leaves some time for topical material:

- Two-state systems
- Bell's inequality, EPR paradox, and hidden variables.

The core material for the Townsend-based progression is:

- Basis states and matrix mechanics operators, eigenstates, and basis transformations.
- Angular momentum eigenstates
- Time evolution and the Schrödinger equation
- Multiple spin states and entanglement: Bell states and EPR paradox
- Density Matrix formalism: pure vs mixed states
- Wave mechanics in 1D

This approach relies on students have a strong background in Linear Algebra, which must be reliably covered in PHY 104A.

PHY 115B — Quantum Mechanics II (4): Continuation of PHY 115A. Angular momentum and spin, central potentials and the hydrogen atom, perturbation theory and scattering.

The material covered in PHY 115B depends on the treatment in 115A: either Griffith-based or Townsend-based (spin first).

The material for the Griffith-based progression are:

- Review particle in a box and harmonic oscillator
- Angular momentum: algebraic methods and spherical harmonics
- Bound states of central potentials: Hydrogen atom
- Spin-orbit coupling and relativistic corrections
- Time-independent perturbation theory
- Time-dependent perturbation theory and scattering
- Quantum field theory for scalar fields

The material for the Townsend-based progression are:

- Review angular momentum
- Particle in a box and quantum tunneling
- Harmonic Oscillator
- Translation and Rotation in 3D
- Symmetries of 2-body problem
- Bound states of central potentials: Hydrogen atom
- Time-independent perturbation theory
- Time-dependent perturbation theory and scattering

The review topics are intended to cover the crucial material that would otherwise be missed for students who took PHY 115A under a different ordering. This situation should be a rare occurrence: instructors tend to teach for multiple years in a row, and students tend to take both courses within the same year.

PHY 115L — Computational Physics 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.

See comments in Section 5 regarding workload for one unit courses. Example topics for assignments include:

- Variations of related problems from PHY 45.
- Symplectic Algorithms
- Extremizing the Action (Gezerlis 5.6)
- Solution of the Time-independent Schrödinger equation: Harmonic oscillator, Lennard-Jones potential (Giordano 10.2).
- Variational Quantum Monte Carlo (Giordano 10.4, Gezerlis 7.8)
- Time-dependent Schrödinger equation: reflection of wave packets (Giordano 10.5)
- Spectral method solutions to Schrödinger equation. (Giordano 10.7)
- Matrix Representation of Interacting spin-half particles (Gezerlis 4.5)
- Analytic solutions to special cases are calculated and used throughout the course to validate the numerical approach.

PHY 117 — Physics Instrumentation with Analog and Digital Electronics (4): 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.

Summary of Course Content: This course provides a theoretical understanding and practical experience with the use of analog and digital electronics within the context of instrumentation for physics experiments.

The lecture content is primarily in support of the lab activities. The lab activities survey the essential devices used for physics instrumentation, excluding passive compenents (resistors, capacitors, and diodes) covered in PHY 80. It excludes modern high-density integrated circuits, such as FPGAs and CPUs, which are covered in PHY 118. The lab topics include: transistors, operational amplifiers, power amplifiers, schmitt triggers, oscillators, gates, flip-flops, combinatorics, synchronous logic, and analog-to-digital and digital-to-analog conversion. There is also room for topical interests of each instructor. The lectures develop physics models for each device which are used to calculate their theoretical behavior, and discuss the ways in which each device contributes to physical instrumentation.

Illustrative Reading: The Art of Electronics by Horowitz and Hill Practical Electronics for Inventors by Scherz Experiments in Modern Physics by Melissinos and Napolitano

Potential Course Overlap: This course has substantial overlap with many courses in electrical and computer engineering, most notably EEC 110A, 110B, 140A, and 18. However, this course is substantially different from any of these courses. Most importantly, this course does not attempt to reach the level of mastery in electronic design that an electrical engineer reaches through years of study and practice. Instead, this is a one quarter survey of the essential analog and digital devices which a scientist is likely to encounter in the context of instrumenting an experiment. This course prepares future scientists with a basic understanding of the operational behavior of these devices which is needed for productive collaboration with engineers to design experiments. We do have an applied physics major in electronic devices which attempts to reach the same level of mastery as engineers in some of these topics. Those students are required to take coursework in EEC instead of taking PHY 117 or 118.

PHY 118 — Physics Instrumentation for Data Acquisition (4): Experimental application of modern high density integrated circuits. Automated data acquisition, microprocessors, field programmable gate arrays.

Summary of Course Content: This course provides practical experience with using modern high-density integrated circuits to develop custom data acquisition circuits for physics experiments.

The lecture content is primarily in support of the lab activities, which deploy FPGAs and microprocessors to create a scalar, function generator, digital oscilloscope, and spectrum analyzier. In order to do so, students learn to write microprocessor code and high level description code for FPGAs. Students use their custom data acquisition system to conduct experiments exploring physical phenomemon such as radioactivity, muon decay, and johnson noise. The lectures further explore the role that data acquisition systems play in modern physics experiments.

Illustrative Reading: A Verilog HDL Primer by Bhasker FPGA Prototyping by VHDL Examples by Chu Getting Started with Arudino by Banzi and Shiloh Experiments in Modern Physics by Melissinos and Napolitano

Potential Course Overlap: This course has substantial overlap with many courses in electrical and computer engineering, most notably EEC 170, 172, 180, and 181A/B. However, this course is substantially different from any of these courses. Most importantly, this course does not attempt to reach the level of mastery in electronic design that an electrical engineer reaches through years of study and practice. Instead, this course covers the basics of programming microprocessors and configuring FPGAs at a level sufficient to instrument basic physics experiments. This course prepares future scientists with a basic understanding of the operational behavior of these essential devices which is needed for productive collaboration with engineers to design experiments. We do have an applied physics major in electronic devices which attempts to reach the same level of mastery as engineers in some topics. Those students are required to take their electronics courses in EEC instead of taking PHY 117 or 118.

12 Implementation

Some aspects of this proposal involve changing the scheduling and number of offerings of certain courses, which does not require campus approval, and the department has already begun to implement those changes in AY 2021-2022. This first year implements changes for juniors and earlier, while allowing seniors to finish under the current schedule. In the tables below, only the courses directly impacted by this proposal are shown.

Changes to the curriculum are tracked in the integrated curriculum management system (ICMS). Each proposed change is approved at the level of UGCC/Vice-Chair, College, and then the Senate Committee on Courses of Instruction (COCI).

All departments with courses that include prerequisites that would be impacted have already been contacted (Electrical and Computer Engineering). We will also reach out to the departments hosting courses for our applied majors: they won't need to make any changes but they might appreciate notification about potential changes to enrollment.

Table 27: Implementation Year One Offerings
Italics: only if college approves in time, Bold: courses offered for seniors. Slashed: Not offered this year.

Fall	Winter	Spring
9HA	9HB	9HC
9HD	~~9HE~~	
40		
	45	
~~102~~	~~104B~~	~~115A~~
104A		104A
	105A	105B
	110A	110B
116A	116B	116C
110C		
112		
115B		

If the new PHY 45 course is not approved in time, we can teach PHY 104B instead. There will be no offering of 115A in the first transition year, as seniors have already taken it, and juniors will not take it until their senior year in the new schedule. The one-unit computing lab courses will not be offered in the first year, as these courses can be taken in the senior year. All three courses of the 116ABC sequence will still be formally offered in the first year, but the content will be adjusted to match the plan: PHY 116A will cover the PHY 80 material, PHY 116B will cover the new 117 content, and PHY 116C will cover the new 118 content. Some students entering 116A will already have taken PHY 80, but for the vast majority, it will have been taught online, with quite different content.

By the second year, the new courses and requirements must be approved to avoid stalling the implementation. The new program is fully implemented:

Table 28: Implementation Year Two Offerings
Slashed: No longer offered.

Fall	Winter	Spring
9HA	9HB	9HC
9HD		
40		
	45	
104A		104A
	105A	105B
~~110C~~	110A	110B
112		
115A	115B	
112L	115L	110L
~~116A~~	~~116B~~	~~116C~~
117	118	

There is a straightforward mapping of new course offerings to time slots in the current program. This should avoid most schedule conflicts. So for instance, the new winter offering of 105A will occupy the time slot for 105B in the current program. The mapping of new course offerings to time slots (by course) in the current program are worked out in Table 29. The remaining tables in this section are useful guides for students during the transition, see Tables 30-35.

Table 29: Mapping of Course Schedule

Course	Current Course Time Slot
starting year one:	
40 (fall)	102 (labs)
	105A (lecture)
45	104B
105A	105B
110AB	Unchanged
104A (spring)	110B
105B	115A
starting year two:	
115A	105A
115B	105B
117	116A
118	116B

Table 30: Example schedule for students in their sophomore year during the transition, having already taken Physics 9HABC. Upper division lab work and electives, including capstones, are not included. Applied physics majors may choose to omit the courses which are not required (105B and 115B) for their major.

Year	Fall	Winter	Spring
Sophomore	9HD(5) M22A(3) 40(3)	105A(4) M22B(3) 45/104B(4)	105B(4) 104A(4) 80(4)
Junior	115A(4) 112+L(5)	115B+L(5) 110A(4)	 110B+L(5)

Table 31: Example schedule for students in their sophomore year during the transition, having already taken Physics 9A. Upper division lab work and electives, including capstones, are not included. Applied physics majors may choose to omit the courses which are not required (105B and 115B) for their major.

Year	Fall	Winter	Spring
Sophomore	M21D(4) 9B(5) 40(3)	M22A(3) 9C(5) 80(4)	M22B(3) 9D(4)
Junior	104A(4)	105A(4) 110A(4) 45(4)	105B(4) 110B+L(5)
Senior	115A(4) 112+L(5)	115B+L(5)	

Table 32: Course Key

40	Introduction to Physics Computation
80	Experimental Techniques
104A	Math Methods
105A/B	Classical Mechanics
45/104B	Computational Physics, **ignore 104A/105A pre-reqs.**
105A/B	Classical Mechanics
110A/B	Electricity and Magnetism, **no more 110C.**
112	Statistical Mechanics
115ABC	Quantum Mechanics

Table 33: Example schedule for students in their junior year during the transition, having already taken Physics 9ABCD. Upper division lab work and electives, including capstones, are not included. Applied physics majors may choose to omit the courses which are not required (105B and 115B) for their major.

Year	Fall	Winter	Spring
Junior	104A(4)	105A(4)	105B(4)
	40(3)	45/104B(4)	80(4)
		110A(4)	110B(4)
Senior	115A(4)	115B+L(5)	
	112+L(5)		

Table 34: Example schedule for students that transfer to UCD as juniors during the transition, having already taken Physics 9ABC. Upper division lab work and electives, including capstones, are not included. Applied physics majors may choose to omit the courses which are not required (105B and 115B) for their major.

Year	Fall	Winter	Spring
Junior	9D(4)	105A(4)	105B(4)
	40(3)	110A(4)	110B(5)
	104A(4)	45/104B(4)	80(4)
Senior	115A(4)	115B+L(5)	
	112+L(5)		

Table 35: Course Key

40	Introduction to Physics Computation
80	Experimental Techniques
104A	Math Methods
105A/B	Classical Mechanics
45/104B	Computational Physics, **ignore 104A/105A pre-reqs.**
105A/B	Classical Mechanics
110A/B	Electricity and Magnetism, **no more 110C.**
112	Statistical Mechanics
115ABC	Quantum Mechanics