Department of Physics

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Physics, one of the basic sciences, has its origin in the irrepressible human curiosity to explore and understand the natural world. This fundamental urge to discover has led to the detailed understanding of a remarkable variety of physical phenomena. Our knowledge now encompasses the large-scale movement of galaxies, the minute motions within atoms and nuclei, and the complex structure of the assemblies of molecules that make life possible. The spectacular expansion of our comprehension of the physical world forms an impressive part of the intellectual and cultural heritage of our times. The opportunity to add to this heritage is an important source of motivation for young physicists. The application of discoveries in physics to the solution of complex modern technological problems offers a vast field in which physicists make decisive contributions. The interplay of pure and applied physics has always been fruitful and today ensures many rewarding career opportunities for physics students.

Carnegie Mellon's undergraduate curriculum in physics has been carefully designed to provide a firm knowledge of the basic principles of physics, an appreciation of a wide range of physical problems of current interest, and the capacity to formulate and solve new problems. In addition to classwork and problem solving, the curriculum includes studying physical phenomena in the laboratory. Physics students are strongly encouraged to go beyond the formal theoretical and experimental course work and become involved in research projects under the guidance of individual faculty members.

Students may choose from a variety of degree options. The objectives and requirements for each of these options are described below. Each allows considerable latitude in the choice of electives:

- B.S. in Physics (p.)
- B.A. in Physics (p.)
- B.S. in Physics with Tracks in: (p.)
  - Applied Physics (p.)
  - Astrophysics (p.)
  - Biological Physics (p.)
  - Chemical Physics (p.)
  - Computational Physics (p.)
- Minor in Physics (p.)

Students pursuing a B.S. in Physics, with any track, will take all courses from the Physics, Mathematics, and Technical Core lists, and take an appropriate selection of courses from the Technical, Non-Technical, Physics Breadth, and Qualifying Physics Elective lists. These lists are detailed below.

- Physics Core (p.)
- Mathematics Core (p.)
- Technical Core (p.)
- Technical Electives (p.)
- Non-Technical Electives (p.)
  - Students entering in the Fall of 2015 and beyond (p.)
  - Students entering prior to the Fall of 2015 (p.)
- Physics Breadth Electives (p.)
- Qualifying Physics Electives (p.)
- Recommended Electives for Graduate School (p.)
- Physics Graduate Courses (p.)

Through the judicious choice of elective courses, a double major program combining physics and another discipline can be readily achieved. A minor in physics is also offered for those students who major in other disciplines. The student, with the help of their faculty advisors, can easily build a program that aims at specific career objectives.

- Physics as an Additional Major (p.)
- Physics as a Dual Degree (p.)
- Minor in Physics (p.)

The Department maintains an active and wide-ranging program of advising. Beyond aiding in academic planning, the department advisors can also assist students in finding research work during the academic year, technical jobs and internships for the summer, as well as planning and executing the necessary steps for gaining employment or continuing their studies beyond the bachelor's degree. Whether students follow a standard curriculum or not, they should consult their academic advisor at least once every semester.

- Sample Schedule for a B.S. in Physics (p.)
- Physics Faculty List (p.)

B.S. in Physics

B.S. degree candidates can choose studies in not only a wide variety of intermediate and advanced topics in physics but also a range of material in other science or engineering fields. The B.S. degree provides a solid foundation for students wishing to go on to graduate work in physics or any of a large number of fields in pure or applied science or engineering, for which a sound grasp of physics and mathematics is essential. This program also provides excellent preparation for careers in teaching, for work in industrial or governmental research and development, or for other employment in business or industry with a significant scientific component.

B.S. Degree Requirements

Physics Core:

All physics majors take these courses in physics, which are designed to teach the fundamentals required for any specialty. Many students take the 100-level courses in their first year of study, the 200-level courses in their second year, and the 300-level courses in their third or fourth year.

		Units
33-121	Physics I for Science Students	12
or 33-151	Matter and Interactions I	
33-142	Physics II for Engineering and Physics Students	12
or 33-152	Matter and Interactions II	
33-104	Experimental Physics	9
33-201	Physics Sophomore Colloquium I	2
33-211	Physics III: Modern Essentials	10
33-231	Physical Analysis	10
33-202	Physics Sophomore Colloquium II	2
33-228	Electronics I	10
33-232	Mathematical Methods of Physics	10
33-234	Quantum Physics	10
33-301	Physics Upperclass Colloquium I	1
33-331	Physical Mechanics I	10
33-338	Intermediate Electricity and Magnetism I	10
33-341	Thermal Physics I	10
33-302	Physics Upperclass Colloquium II	1
33-340	Modern Physics Laboratory	10
Total Physics Core Units		129

Mathematics Core:

All physics majors take these calculus courses from the Department of Mathematics to support their studies in physics.

		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-259	Calculus in Three Dimensions	9
Total Mathematics Core Units		29

Technical Core:

All students in the Mellon College of Science take courses in the Life Sciences, Physical Sciences, and Mathematics, Statistics, or Computer Science to gain the technical breadth necessary for interdisciplinary work. The following three courses have been selected specifically for physics majors to give them the technical breadth they need.

		Units
03-121	Modern Biology [1]	9
09-105	Introduction to Modern Chemistry I [2]	10

15-110	Principles of Computing [3]	10-12
or 15-112	Fundamentals of Programming and Computer Science	
or		
02-201	Programming for Scientists (only if taken in 2016-2017 academic year)	
Total Technical Core Units		29-31

[1] If 03-121 is satisfied through placement credit, students entering in the Fall of 2015 or later should refer to the Mellon College of Science's Life Sciences list to fulfill technical breadth requirement A.

[2] If 09-105 is satisfied through placement credit, students entering in the Fall of 2015 or later should refer to the Mellon College of Science's Physical Sciences list to fulfill technical breadth requirement B.

[3] If 15-112 is satisfied through placement credit, students entering in the Fall of 2015 or later should refer to the Mellon College of Science's STEM Course list to fulfill technical breadth requirement D.

Technical Electives:

Physics majors can choose to increase the breadth or depth of their studies through their choices of Technical Electives. Students may choose these electives individually or may take a pre-set selection of technical electives known as a "track" to focus on a specific subfield of physics. **The 5 available tracks are detailed below.**

		Units
33-xxx	Physics Breadth Elective	9-12
33-xxx	3 Qualifying Physics Electives	27-37
21-2xx	Mathematics Elective	9-10
xx-xxx	3 STEM Electives [4]	27-36
Total Technical Electives Units		72-95

[4] STEM electives are any courses in MCS (including Physics), SCS, Statistics, CIT, and others explicitly approved by the Assistant Head for Undergraduate Affairs.

Non-Technical Electives: Students Entering in the Fall of 2015 and Beyond:

The Mellon College of Science requires that all students take a variety of non-technical courses to strengthen their understanding of both themselves and the world at large. The precise requirements are different for those entering before and after the Fall of 2015.

		Units
99-101	Computing @ Carnegie Mellon	3
76-101	Interpretation and Argument	9
38-101	EUREKA!: Discovery and Its Impact	6
38-110	ENGAGE in Service	1
38-220	ENGAGE in the Arts	2
38-230	ENGAGE in Wellness: Looking Inward	1
38-330	ENGAGE in Wellness: Looking Outward	1
38-301	MCS Junior Seminar	6
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Cultural/Global Understanding Elective [5]	9
xx-xxx	4 Non-Technical Electives [6]	36
Total Non-Technical Units		75

[5] Refer to the Mellon College of Science's Cultural/Global Understanding list for courses that will fulfill this requirement. Placement credit may not be used.

[6] Refer to the Mellon College of Science's Arts, Humanities, and Social Sciences section for courses that will fulfill the non-technical electives requirement. Up to 18 units may be fulfilled through placement credit.

Non-Technical Electives: Students Entering Prior to the Fall of 2015:

The Mellon College of Science requires that all students take a variety of non-technical courses to strengthen their understanding of both themselves and the world at large. The precise requirements are different for those entering before and after the Fall of 2015.

		Units
99-101	Computing @ Carnegie Mellon	3
76-101	Interpretation and Argument	9
xx-xxx	Congnition, Choice, Behavior Elective [7]	9
xx-xxx	Economic, Political, and Social Institutions Elective [7]	9
xx-xxx	Cultural Analysis Elective [7]	9
xx-xxx	4 Non-Technical Electives [7]	36
Total Non-Technical Units		75

[7] Refer to the Mellon College of Science's Humanities, Social Sciences, and Fine Arts Requirements section for courses that will fulfill the Cognition, Choice, and Behavior Elective, the Economic, Political, and Social Institutions Elective, the Cultural Analysis Elective, and the 4 Non-Technical Electives.

Free Electives:

All students must complete a minimum of 360 units to earn a bachelor's degree in the Mellon College of Science. Students are welcome to take more than the minimum 360 units required.

		Units
xx-xxx	Free Electives [8]	1-26
Total Free Elective Units		1-26

[8] A maximum of 9 units of physical education and/or military science and/or STUCO courses may be taken as free electives.

Physics Electives

Physics Breadth Electives

Students pursuing a B.S. in Physics must take at least one course from the Physics Breadth Elective list to gain experience in a subfield of physics. Some tracks have this course prescribed, while others allow free choice from this list. All of these courses may also be taken as Qualifying Physics Electives, but they may not fulfill both requirements simultaneously. Certain courses are offered only in alternate years, as indicated.

- 33-224 Stars, Galaxies and the Universe
- 33-353 Intermediate Optics (Alt. Fall- F16, F18)
- 33-355 Nanoscience and Nanotechnology (Alt. Fall- F17, F19)
- 33-441 Introduction to BioPhysics
- 33-444 Introduction to Nuclear and Particle Physics
- 33-448 Introduction to Solid State Physics
- 33-466 Extragalactic Astrophysics and Cosmology
- 33-467 Astrophysics of Stars and the Galaxy
- 33-650 General Relativity
- 33-658 Quantum Computation and Quantum Information Theory (Alt. Spring- S18, S20)

Total Physics Breadth Elective Units

Qualifying Physics Electives

Students pursuing a B.S. in Physics must take at least three courses totaling at least 27 units from the Qualifying Physics Elective list, not including the 100-level courses. Some tracks have these courses prescribed, while others allow free choice from this list, allowing students to choose between broad and in-depth study. Students pursuing a B.A. in Physics must take at least two courses totaling at least 18 units from this list. Students pursuing a Minor in Physics must take at least three courses totaling at least 27 units from this list or non-prescribed courses from the Physics Core list. While all courses on the Physics Breadth Elective list are also on the Qualifying Physics Elective list, a course may not fulfill both requirements simultaneously. Certain courses are offered only in alternate years, as indicated.

- 33-114 Physics of Musical Sound (B.A. and Minor only)[9]
- 33-120 Science and Science Fiction (B.A. and Minor only)[9]
- 33-224 Stars, Galaxies and the Universe
- 33-241 Introduction to Computational Physics
- 33-332 Physical Mechanics II
- 33-339 Intermediate Electricity and Magnetism II
- 33-342 Thermal Physics II
- 33-350 Undergraduate Research [10]
- 33-353 Intermediate Optics (Alt. Fall- F16, F18)

- 33-355 Nanoscience and Nanotechnology (Alt. Fall- F17, F19)
- 33-398 Special Topics
- 33-441 Introduction to BioPhysics
- 33-444 Introduction to Nuclear and Particle Physics
- 33-445 Advanced Quantum Physics I
- 33-446 Advanced Quantum Physics II
- 33-448 Introduction to Solid State Physics
- 33-451 Senior Research[10]
- 33-456 Advanced Computational Physics
- 33-466 Extragalactic Astrophysics and Cosmology
- 33-467 Astrophysics of Stars and the Galaxy
- 33-499 Supervised Reading [10]
- 33-650 General Relativity
- 33-658 Quantum Computation and Quantum Information Theory (Alt. Spring- S18, S20)
- 33-7xx Physics Graduate Level Courses (see list below)

Total Qualifying Physics Electives Units	

[9] Only one of these two courses (33-114 and 33-120) may be used for the B.A.

[10] Only one of these three courses (33-350, 33-451, and 33-499) may be used as a Qualifying Physics Elective. Any exceptions must be approved by the Assistant Head for Undergraduate Affairs.

Qualifying Physics Electives Recommended for Graduate School

Students planning to undertake graduate studies in physics are strongly advised to take the following courses, which count as Qualifying Physics Electives and STEM Electives.

- 33-332 Physical Mechanics II
- 33-339 Intermediate Electricity and Magnetism II
- 33-445 Advanced Quantum Physics I
- 33-446 Advanced Quantum Physics II

Qualifying Physics Electives Recommended for Graduate School	Optional

Physics Graduate Courses

These courses are intended for graduate students in physics, but may be taken by advanced undergraduates as Qualifying Physics or STEM Electives.

- 33-755 Quantum Mechanics I
- 33-756 Quantum Mechanics II
- 33-758 Quantum Computation and Quantum Information Theory
- 33-759 Introduction to Mathematical Physics I
- 33-761 Classical Electrodynamics I
- 33-762 Classical Electrodynamics II
- 33-765 Statistical Mechanics
- 33-767 Biophysics: From Basic Concepts to Current Research
- 33-769 Quantum Mechanics III: Many Body and Relativistic Systems
- 33-770 Field Theory I
- 33-771 Field Theory II
- 33-777 Introductory Astrophysics
- 33-779 Introduction to Nuclear and Particle Physics
- 33-780 Nuclear and Particle Physics II
- 33-783 Solid State Physics

Physics Graduate Course Units	

B.S. in Physics – Sample Schedule (No Track)

BEGINNING FALL 2015 AND BEYOND

(For the previous catalog, visit http://coursecatalog.web.cmu.edu/previous/2014-2015/melloncollegeofscience/departmentofphysics/)

First Year

Fall		Units
99-101	Computing @ Carnegie Mellon	3
38-101	EUREKA!: Discovery and Its Impact	6
33-121	Physics I for Science Students	12
or 33-151	Matter and Interactions I	
21-120	Differential and Integral Calculus	10
xx-xxx	MCS/Physics Technical Core Requirement 1 of 3 (03-121, 09-105, or 15-110/15-112)	9-12
76-101	Interpretation and Argument	9
or 76-100	Reading and Writing in an Academic Context	
First-Year Fall Units		49-52

Spring		Units
33-142	Physics II for Engineering and Physics Students	12
or 33-152	Matter and Interactions II	
33-104	Experimental Physics	9
21-122 21-37	Integration and Approximation	10
xx-xxx	MCS/Physics Technical Core Requirement 2 of 3 (03-121, 09-105, or 15-110/15-112)	9-12
76-101	Interpretation and Argument xx-xxx::Non-Technical elective 1 of 4	9
First-Year Spring Units		49-52

Sophomore Year

Fall		Units
33-201	Physics Sophomore Colloquium I	2
33-211	Physics III: Modern Essentials	10
33-231	Physical Analysis	10
21-259	Calculus in Three Dimensions	9
xx-xxx	MCS/Physics Technical Core Requirement 3 of 3 (03-121, 09-105, 15-110/15-112)	9-12
38-110	ENGAGE in Service	1
38-220	ENGAGE in the Arts	2
xx-xxx	Cultural/Global Understanding Elective	9-12
Sophomore Fall Units		52-58

Spring		Units
38-230	ENGAGE in Wellness: Looking Inward	1
33-202	Physics Sophomore Colloquium II	2
33-228	Electronics I	10
33-232	Mathematical Methods of Physics	10
33-234	Quantum Physics	10
xx-xxx	Technical Elective 1 of 8	9-12
Sophomore Spring Units		42-45

Junior Year

Fall		Units
38-330	ENGAGE in Wellness: Looking Outward	1
33-301	Physics Upperclass Colloquium I	1
33-331	Physical Mechanics I	10
33-338	Intermediate Electricity and Magnetism I	10
33-341	Thermal Physics I	10
xx-xxx	Technical Elective 2 of 8	9-12
Junior Fall Units		41-44

Spring		Units
38-301	MCS Junior Seminar Optional	6
33-302	Physics Upperclass Colloquium II	1
33-340	Modern Physics Laboratory	10
xx-xxx	Technical Elective 3 of 8	9-12
xx-xxx	Technical Elective 4 of 8	9-12
xx-xxx	Non-Technical Elective 2 of 4	9-12
Junior Spring Units		44-53

Senior Year

Fall		Units
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Technical Elective 5 of 8	9-12
xx-xxx	Technical Elective 6 of 8	9-12
xx-xxx	Non-Technical Elective 3 of 4	9-12
xx-xxx	Free Elective	9-12
xx-xxx	Free Elective	9-12
Senior Fall Units		46-61

Spring		Units
xx-xxx	Technical Elective 7 of 8	9-12
xx-xxx	Technical Elective 8 of 8	9-12
xx-xxx	Non-Technical Elective 4 of 4	9-12
xx-xxx	Free Elective	9-12
Senior Spring Units		36-48

B.A. in Physics

The Bachelor of Arts degree in Physics offers a flexible program that allows students to combine the study of Physics with the opportunity to do intensive work in substantive areas such as liberal arts, teaching, business or law. With 82 units of free electives, it is feasible for students to obtain, for example, a double major with a department in the Dietrich College of Humanities and Social Sciences, the College of Fine Arts, or the Tepper School of Business. It is expected that students will focus their elective courses in a well-defined academic area. Students must meet with the Assistant Head for Undergraduate Affairs and construct an approved plan of study.

The requirements for the B.A. degree are the same as for the B.S. degree, except that 6 of the Physics, Mathematics and Technical Electives in the B.S. program become Free Electives in the BA program. These requirements are listed below.

B.A. Degree Requirements

Physics Core:

All physics majors take these courses in physics, which are designed to teach the fundamentals required for any specialty. Many students take the 100-level courses in their first year of study, the 200-level courses in their second year, and the 300-level courses in their third or fourth year.

		Units
33-121	Physics I for Science Students	12
or 33-151	Matter and Interactions I	
33-142	Physics II for Engineering and Physics Students	12
or 33-152	Matter and Interactions II	
33-104	Experimental Physics	9
33-201	Physics Sophomore Colloquium I	2
33-211	Physics III: Modern Essentials	10
33-231	Physical Analysis	10
33-202	Physics Sophomore Colloquium II	2
33-228	Electronics I	10
33-232	Mathematical Methods of Physics	10
33-234	Quantum Physics	10
33-301	Physics Upperclass Colloquium I	1
33-331	Physical Mechanics I	10
33-338	Intermediate Electricity and Magnetism I	10
33-341	Thermal Physics I	10
33-302	Physics Upperclass Colloquium II	1
33-340	Modern Physics Laboratory	10
Total Physics Core Units		129

Mathematics Core:

All Physics Majors take these courses from the Department of Mathematics to support their studies in Physics.

		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-259	Calculus in Three Dimensions	9
Total Mathematics Core Units		29

Technical Core:

All students in the Mellon College of Science take courses in the Life Sciences, Physical Sciences, and Mathematics, Statistics, or Computer Science to gain the technical breadth necessary for interdisciplinary work. These three courses have been selected specifically for Physics Majors to give them the technical breadth they need

		Units
03-121	Modern Biology [17]	9
09-105	Introduction to Modern Chemistry I [18]	10
15-112	Fundamentals of Programming and Computer Science [19]	10-12
or 15-110	Principles of Computing	
or		
02-201	Programming for Scientists (only if taken in 2016-2017 academic year)	
Total Technical Core Units		29-31

[17] If 03-121 is satisfied through placement credit, students entering in the Fall of 2015 or later should refer to the Mellon College of Science's Life Sciences list to fulfill technical breadth requirement A.

[18] If 09-105 is satisfied through placement credit, students entering in the Fall of 2015 or later should refer to the Mellon College of Science's Physical Sciences list to fulfill technical breadth requirement B.

[19] If 15-112 is satisfied through placement credit, students entering in the Fall of 2015 or later should refer to the Mellon College of Science's STEM Course list to fulfill technical breadth requirement D.

Technical Electives:

While students pursuing a B.S. in Physics are required to take a minimum of 8 Physics, Mathematics, and STEM electives, students pursuing a B.A. in Physics need only take a minimum of 2 Qualifying Physics Electives.

		Units
33-xxx	2 Qualifying Physics Electives	18-24
Total Technical Electives		18-24

Non-Technical Electives: Students Entering in the Fall of 2015 and Beyond:

The Mellon College of Science requires that all students take a variety of non-technical courses to strengthen their understanding of both themselves and the world at large. The precise requirements are different for those entering before and after the Fall of 2015.

		Units
99-101	Computing @ Carnegie Mellon	3
76-101	Interpretation and Argument	9
38-101	EUREKA!: Discovery and Its Impact	6
38-110	ENGAGE in Service	1
38-220	ENGAGE in the Arts	2
38-230	ENGAGE in Wellness: Looking Inward	1
38-330	ENGAGE in Wellness: Looking Outward	1
38-301	MCS Junior Seminar	6
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Cultural/Global Understanding Elective [20]	9
xx-xxx	4 Non-Technical Electives [21]	36
Total Non-Technical Elective Units		75

[20] Refer to the Mellon College of Science's Cultural/Global Understanding list for courses that will fulfill this requirement. Placement credit may not be used.

[21] Refer to the Mellon College of Science's Arts, Humanities, and Social Sciences section for courses that will fulfill the non-technical electives requirement. Up to 18 units may be fulfilled through placement credit.

Non-Technical Electives: Students Entering Prior to the Fall of 2015:

The Mellon College of Science requires that all students take a variety of non-technical courses to strengthen their understanding of both themselves and the world at large. The precise requirements are different for those entering before and after the Fall of 2015.

		Units
99-101	Computing @ Carnegie Mellon	3
76-101	Interpretation and Argument	9
xx-xxx	Congnition, Choice, Behavior Elective [22]	9
xx-xxx	Economic, Political, and Social Institutions Elective [22]	9
xx-xxx	Cultural Analysis Elective [22]	9
xx-xxx	4 Non-Technical Electives [22]	36
Total Non-Technical Elective Units		75

[22] Refer to the Mellon College of Science's Humanities, Social Sciences, and Fine Arts Requirements section for courses that will fulfill the Cognition, Choice, and Behavior Elective, the Economic Political, and Social Institutions Elective, the Cultural Analysis Elective, and the 4 Non-Technical Electives.

Free Electives:

All students must complete a minimum of 360 units to earn a bachelor's degree in the Mellon College of Science. Students are welcome to take more than the minimum 360 units required. The B.A. in Physics replaces 6 Technical Electives with Free Electives, compared to the B.S. in Physics.

		Units
xx-xxx	Free Electives [23]	72-80
Tota Free Electives		72-80

[23] A maximum of 9 units of physical education and/or military science and/or STUCO courses may be taken as free electives.

Tracks for B.S. in Physics

Students seeking a B.S. in Physics may choose from 5 different Physics tracks, or opt to pursue no track. Each of these tracks fulfills the Technical Electives of the B.S. in Physics. The available tracks are:

- Applied Physics (p.)
- Astrophysics (p.)
- Biological Physics (p.)
- Chemical Physics (p.)
- Computational Physics (p.)

The track descriptions and requirements are listed below.

B.S. in Physics / No Track:

Physics students wanting maximum freedom can opt not to select a track. The required Technical Electives are those described in the B.S. in Physics section above, and are reprinted below.

		Units
33-xxx	Physics Breadth Elective	9-12
33-xxx	3 Qualifying Physics Electives	27-37
21-2xx	Mathematics Elective	9-10
xx-xxx	3 STEM Electives [11]	27-36
Total Technical Elective Units		72-95

[11] STEM electives are any courses in MCS (including Physics), SCS, Statistics, CIT, and others explicitly approved by the Assistant Head for Undergraduate Affairs.

B.S. in Physics / Applied Track:

The B.S. in Physics/Applied Physics Track is designed primarily for students who want to prepare for a career path that takes advantage of the diverse and expanding opportunities for employment in industrial and government laboratories with a B.S. degree. The program provides a solid foundation in the concepts of physics, as well as giving the student the experience and understanding of the application of these concepts. The track is intended to enhance computing and laboratory skills, and to introduce the application of physics to those subjects of particular interest to the student. Since the possible subject areas for study are so varied, the track will be tailored to each student's needs within the framework described below.

		Units
33-448	Introduction to Solid State Physics	9
xx-xxx	Computational Science Course [12]	9-12
21-2xx	4 Applied Physics/Laboratory Electives [12]	36-48
33-350 or 33-451	Undergraduate Research [12] Senior Research	9-15
21-2xx	Mathematics Elective [12]	9-10
Total Applied Track Elective Units		72-94

[12] The elective courses and research topic are decided after consultation with, and approval by, the Assistant Head for Undergraduate Affairs.

B.S. in Physics / Astrophysics Track:

The B.S. in Physics/Astrophysics Track provides an option for those Physics majors who either want to specialize in this subfield or plan careers in astronomy or astrophysics. Career paths may include postgraduate training in astronomy or astrophysics or proceeding directly to jobs in these fields. The program provides a thorough foundation in the core physics program with electives concentrating in astrophysics.

		Units
33-224	Stars, Galaxies and the Universe	9
33-466	Extragalactic Astrophysics and Cosmology	9
33-467	Astrophysics of Stars and the Galaxy	9
33-350 or 33-451	Undergraduate Research [13] Senior Research	9-15
21-2xx	Mathematics Elective	9-10
xx-xxx	3 STEM Electives	27-36
Total Astrophysics Track Elective Units		72-88

[13] The research topic must be approved by the Assistant Head for Undergraduate Affairs.

B.S. in Physics / Biological Physics Track:

The B.S. in Physics/Biological Physics Track combines a rigorous foundation in undergraduate physics with courses in Biological Physics and Chemistry. It is particularly suitable for students preparing for post-baccalaureate careers in the expanding areas of biological and medical physics or for graduate study in biophysics. The program is sufficiently flexible that it can be readily adapted to the requirements of individual students. The student will first meet with the Assistant Head for Undergraduate Affairs to discuss interests and career goals and then choose electives that fulfill the requirements of the track.

The Biological Physics Track includes a number of courses that are also requirements for the pre-medical program. Students interested in both the Biological Physics Track and the pre-medical program should consult with both the Assistant Head for Undergraduate Affairs in the Physics Department and the Director of the Health Professions Program for help in planning their programs.

		Units
33-441 or 03-439	Introduction to BioPhysics Introduction to Biophysics	9-10
33-xxx	1 Qualifying Physics Elective	9-12
21-2xx	Mathematics Elective	9-10
03-231	Biochemistry I	9
09-217	Organic Chemistry I	9
09-218	Organic Chemistry II	9
03-xxx	2 Biological Sciences Electives [14]	18
Total Biological Physics Track Elective Units		72-77

[14] The elective courses in Biological Sciences are decided after consultation with, and approval by, the Assistant Head for Undergraduate Affairs.

B.S. in Physics / Chemical Physics Track:

The B.S. in Physics/Chemical Physics Track is designed for students wishing to have a strong grounding in physics along with a specialization in physical chemistry and/or chemical physics. It is particularly suitable for those students planning on graduate studies in physics with an emphasis on chemical physics or chemistry. The program is sufficiently flexible that it can be readily adapted to the requirements of individual students. The student will first meet with the Assistant Head for Undergraduate Affairs to discuss interests and career goals and then choose electives that fulfill the requirements of the track.

The Chemical Physics Track incorporates a number of courses that are also requirements for the pre-medical program. Students interested in both the Chemical Physics Track and the pre-medical program should consult both with their Physics Department advisor and the Director of the Health Professions Program for help in planning their programs.

		Units
33-xxx	1 Physics Breadth Elective	9-12
21-2xx	Mathematics Elective	9-10
09-106	Modern Chemistry II	10
09-344	Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry	9
09-345	Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry	9
09-xxx	3 Chemistry Electives [15]	27
Total Chemical Physics Track Elective Units		73-77

[15] The elective courses in Chemistry are decided after consultation with, and approval by, the Assistant Head for Undergraduate Affairs.

B.S. in Physics / Computational Physics Track:

The B.S. in Physics/Computational Physics Track is intended to fill the increasing demand for physics graduates who are skilled in computational and numerical techniques which are used in the analysis of physical problems and in subjects ranging from control and real-time programming to software engineering and compiler and operating systems design. The degree provides the student with a rigorous grounding in physics as well as in the foundations and practice of computer use as applied to scientific problems. Work is done on machines ranging from high-level workstations through supercomputers.

		Units
33-241	Introduction to Computational Physics	9
33-456	Advanced Computational Physics	9
33-xxx	1 Physics Breadth Elective	9-12
33-xxx	1 Qualifying Physics Elective	9-12
21-127	Concepts of Mathematics	10
21-369	Numerical Methods	9
15-122	Principles of Imperative Computation [16]	10
15-150	Principles of Functional Programming [16]	10
Total Computational Physics Track Elective Units		75-81

[16] The student must check with the Assistant Head for Undergraduate Affairs to confirm that these are the latest required Computer Science courses for this track.

Additional Major or Dual Degree in Physics with a Degree in Another Department

Physics may be taken as an additional major (also known as a “double major”) or as a second degree, with another department granting the primary degree. The rules of the Physics Department for these two options are distinct, as discussed below.

Additional Major

In order to receive an Additional Major in Physics, with another department granting the primary degree — with a B.S. or B.A., alone or with any track — all requirements of the Physics degree and the particular physics track, as listed in the previous sections, must be fulfilled except:

- No STEM Electives are required
- No Non-Technical Electives are required
- 03-121 Modern Biology is not required
- 09-105 Introduction to Modern Chemistry I is not required
- No Free Electives are required

The full requirements are described below:

Physics Core:

All physics majors take these courses in physics, which are designed to teach the fundamentals required for any specialty. Many students take the 100-level courses in their first year of study, the 200-level courses in their second year, and the 300-level courses in their third or fourth year.

		Units
33-121	Physics I for Science Students	12
or 33-151	Matter and Interactions I	
33-142	Physics II for Engineering and Physics Students	12
or 33-152	Matter and Interactions II	
33-104	Experimental Physics	9
33-201	Physics Sophomore Colloquium I	2
33-211	Physics III: Modern Essentials	10
33-231	Physical Analysis	10
33-202	Physics Sophomore Colloquium II	2
33-228	Electronics I	10
33-232	Mathematical Methods of Physics	10
33-234	Quantum Physics	10
33-301	Physics Upperclass Colloquium I	1
33-331	Physical Mechanics I	10
33-338	Intermediate Electricity and Magnetism I	10
33-341	Thermal Physics I	10
33-302	Physics Upperclass Colloquium II	1
33-340	Modern Physics Laboratory	10
Total Physics Core Units		129

Mathematics Core:

All physics majors take these calculus courses from the Department of Mathematics to support their studies in physics.

		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-259	Calculus in Three Dimensions	9
Total Mathematics Core Units		29

Technical Core for an Additional Major:

Students pursuing an additional major in physics do not need to fulfill the full Technical Core required by the Mellon College of Science, but are still required to take either 15-110 or 15-112 (or an equivalent course as pre-approved by the Associate Dean of the Mellon College of Science).

		Units
15-110	Principles of Computing	10-12
or 15-112	Fundamentals of Programming and Computer Science	
or		
02-201	Programming for Scientists (only if taken in 2016-2017 academic year)	
Total Technical Core Units		10-12

Technical Electives for an Additional Major:

Students pursuing an additional major in physics must take the Physics Electives and Mathematics Elective required of physics as the primary major, but do not need to take the STEM electives. Students may choose these electives individually, but are encouraged to consider the Physics Tracks (p.) described in the B.S. in Physics section as sets of courses that are designed to support specific career goals.

		Units
33-xxx	Physics Breadth Elective	9-12
33-xxx	3 Qualifying Physics Electives	27-37
21-2xx	Mathematics Elective	9-10
Total Technical Electives		45-59

Dual Degree

In order to receive a Dual Degree in another subject and Physics, all requirements of the Physics degree must be fulfilled. Students may choose to complete the B.A. or the B.S. in Physics, with or without a track. Students must complete both the technical and non-technical requirements, and should consult with the Assistant Head for Undergraduate Affairs for questions about double counting. The number of units required is 90 more than the total units required by the department requiring the fewer total units. Since Physics requires 360 units, the lowest possible minimum for a Dual Degree with Physics is 450 units.

Minor in Physics

The Minor in Physics is designed to provide a solid foundation in physics at the introductory level, followed by elective courses which will familiarize the student with areas of modern physics, and the concepts and techniques employed therein. The physics minor requires seven courses of at least 9 units each, of which four are required and three are electives.

The Minor is open to all students in the university, but students with non-calculus-based majors should be aware of the mathematics requirements for many physics courses (21-120, 21-122, and 21-259).

		Units
33-121	Physics I for Science Students	12
or 33-141	Physics I for Engineering Students	
or 33-151	Matter and Interactions I	
33-122	Physics II for Biological Sciences and Chemistry Students	12
or 33-142	Physics II for Engineering and Physics Students	
or 33-152	Matter and Interactions II	
33-104	Experimental Physics	9
33-211	Physics III: Modern Essentials	10
33-xxx	3 Qualifying Physics Electives or Physics Core Electives [24]	27-37
Total Physics Minor Units		70-80

[24] The physics electives are decided after consultation with, and approval by, the Assistant Head for Undergraduate Affairs. Students may take courses from the Qualifying Physics List or additional courses from the Physics Core list, such as Quantum Physics or Electronics I.

Faculty

DAVID ANDERSON, Assistant Teaching Professor of Physics – Ph.D., University of York (UK) ; Carnegie Mellon, 2008–.
ROY A. BRIERE, Professor of Physics – Ph.D., University of Chicago; Carnegie Mellon, 1999–.
RUPERT CROFT, Professor of Physics – Ph.D., Oxford University; Carnegie Mellon, 2001–.
MARKUS DESERNO, Professor of Physics – Ph. D., University of Mainz, Germany; Carnegie Mellon, 2007–.
SERGEY KOPOSOV, Assistant Professor of Physics – Ph.D., University of Heidelberg; Carnegie Mellon ; Carnegie Mellon, 2016-–.
TIZIANA DI MATTEO, Professor of Physics – Ph.D., University of Cambridge; Carnegie Mellon, 2004–.
ALEX EVILEVITCH, Associate Professor of Physics – Ph.D., Lund University, Sweden; Carnegie Mellon, 2009–.
RANDALL M. FEENSTRA, Professor of Physics – Ph.D., California Institute of Technology; Carnegie Mellon, 1995–.
GREGG B. FRANKLIN, Professor of Physics – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1984–.
STEPHEN GAROFF, Professor of Physics; Head, Department of Physics – Ph.D., Harvard University; Carnegie Mellon, 1988–.
KUNAL GHOSH, Teaching Professor of Physics, Assistant Head for Undergraduate Affairs, Department of Physics – Ph.D., Iowa State University; Carnegie Mellon, 2001–.
FREDERICK J. GILMAN, Buhl Professor of Physics – Ph.D., Princeton University; Carnegie Mellon, 1995–.
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GEORGE KLEIN, Associate Teaching Professor of Physics – Ph.D., New York University; Carnegie Mellon, 1993–.
MICHAEL J. LEVINE, Professor of Physics, Director of Pittsburgh Supercomputer Center – Ph.D., California Institute of Technology; Carnegie Mellon, 1968–.
MATHIAS LOSCHE, Professor of Physics – Ph.D., Technical University of Munich; Carnegie Mellon, 2005–.
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CURTIS A. MEYER, Professor of Physics; Associate Dean, Mellon College of Science; – Ph.D., University of California, Berkeley; Carnegie Mellon, 1993–.
COLIN J. MORNINGSTAR, Professor of Physics – Ph.D., University of Toronto; Carnegie Mellon, 2000–.
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BRIAN P. QUINN, Professor of Physics – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1988–.
IRA Z. ROTHSTEIN, Professor of Physics – Ph.D., University of Maryland at College Park; Carnegie Mellon, 1997–.
JAMES S. RUSS, Professor of Physics – Ph.D., Princeton University; Carnegie Mellon, 1967–.
REINHARD A. SCHUMACHER, Professor of Physics – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1987–.
ROBERT M. SUTER, Professor of Physics – Ph.D., Clark University; Carnegie Mellon, 1981–.
ROBERT H. SWENDSEN, Professor of Physics – Ph.D., University of Pennsylvania; Carnegie Mellon, 1984–.
HY TRAC, Associate Professor of Physics – Ph.D., University of Toronto; Carnegie Mellon, 2010–.
HELMUT VOGEL, Professor of Physics – Ph.D., University of Erlangen-Nuremberg; Carnegie Mellon, 1983–.
MATTHEW WALKER, Assistant Professor of Physics – Ph.D., University of Michigan; Carnegie Mellon, 2013–.
MICHAEL WIDOM, Professor of Physics – Ph.D., University of Chicago; Carnegie Mellon, 1985–.
DI XIAO, Associate Professor of Physics – Ph.D., University of Texas, Austin; Carnegie Mellon, 2012–.

Emeriti Faculty

LUC BERGER, Professor of Physics, Emeritus – Ph.D., University of Lausanne, Switzerland; Carnegie Mellon, 1960–.
RICHARD M. EDELSTEIN, Professor of Physics, Emeritus – Ph.D., Columbia University; Carnegie Mellon, 1960–.
ARNOLD ENGLER, Professor of Physics, Emeritus – Ph.D., University of Berne, Switzerland; Carnegie Mellon, 1962–.

THOMAS A. FERGUSON, Professor of Physics – Ph.D., University of California at Los Angeles; Carnegie Mellon; Carnegie Mellon, 1985–.
JOHN G. FETKOVICH, Professor of Physics, Emeritus – Ph.D., Carnegie Mellon University; Carnegie Mellon, 1959–.
RICHARD GRIFFITHS, Professor of Physics, Emeritus – Ph.D., University of Leicester, U.K.; Carnegie Mellon, 1996–.
ROBERT GRIFFITHS, University Professor of Physics, Emeritus – Ph.D, Stanford University; Carnegie Mellon, 1962–.
RICHARD F. HOLMAN, Professor of Physics, Emeritus – Ph.D., John Hopkins University; Carnegie Mellon; Carnegie Mellon, 1987–.
LEONARD S. KISSLINGER, Professor of Physics, Emeritus – Ph.D., Indiana University; Carnegie Mellon, 1969–.
ROBERT W. KRAEMER, Professor of Physics, Emeritus – Ph.D., Johns Hopkins University; Carnegie Mellon, 1965–.
LING-FONG LI, Professor of Physics, Emeritus – Ph.D., University of Pennsylvania; Carnegie Mellon, 1974–.
JOHN F. NAGLE, Professor of Physics, Emeritus – Ph.D., Yale University; Carnegie Mellon, 1967–.
ROBERT T. SCHUMACHER, Professor of Physics, Emeritus – Ph.D., University of Illinois; Carnegie Mellon, 1957–.
ROBERT F. SEKERKA, University Professor of Physics and Mathematics, Emeritus – Ph.D., Harvard ; Carnegie Mellon, 1969–.
NED S. VANDER VEN, Professor of Physics, Emeritus – Ph.D., Princeton University; Carnegie Mellon, 1961–.

Joint Appointments and Courtesy Appointments

SHELLEY ANNA, Professor of Mechanical and Chemical Engineering – Ph.D., Harvard University; Carnegie Mellon, 2003–.
DAVID GREVE, Professor of Electrical & Computer Engineering – Ph.D., Lehigh University; Carnegie Mellon, 1982–.
MOHAMMAD F. ISLAM, Associate Research Professor of Materials Science & Engineering – Ph.D., University of Pennsylvania; Carnegie Mellon, 2005–.
MICHAEL E. MCHENRY, Professor of Materials Science and Engineering – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1989–.
ANTHONY D. ROLLETT, Professor of Materials Science & Engineering – Ph.D., Drexel University; Carnegie Mellon, 1995–.
JIAN-GANG ZHU, Professor of Electrical and Computer Engineering – Ph.D., University of California San Diego; Carnegie Mellon, 1997–.