

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. The deep understanding of the physical world developed by physics majors prepares them for success in a wide variety of careers well beyond physics, from medicine to all the sciences and engineering.

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. 1)
- B.A. in Physics (p. 3)
- B.S. in Physics with Tracks in: (p. 4)
 - Applied Physics
 - Astrophysics
 - Biological Physics
 - Chemical Physics
 - Computational Physics
 - Quantum Physics
- Minor in Physics (p. 7)

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. 1)
- Mathematics Core (p. 1)
- Technical Core (p. 1)
- Technical Electives (p. 4)
- Non-Technical Electives (<http://coursecatalog.web.cmu.edu/schools-colleges/melloncollegeofscience/#generaleducationrequirementstext>)
- Physics Breadth Electives (p. 4)
- Qualifying Physics Electives (p. 4)
- Recommended Electives for Physics Graduate School (p. 4)
- Physics Graduate Courses (p. 4)

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. 6)
- Physics as a Dual Degree (p. 6)
- Minor in Physics (p. 7)

The Department maintains an active and wide-ranging program of advising. Beyond aiding in academic planning, the Director of Undergraduate Affairs 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. 1)

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.

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	
Corequisite for 33-121 is 21-120		
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	10
Total Mathematics Core Units		30

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	

Total Technical Core Units 29-31

[1] If 03-121 is satisfied through placement credit, students 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 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 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 six available tracks are detailed here.**

		Units
33-xxx	Physics Breadth Elective	9-12
33-xxx	Three Qualifying Physics Electives	27-36
21-2xx	Mathematics Elective	9-10
xx-xxx	Three STEM Electives ⁴	27-36

Total Technical Electives Units 72-94

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

Non-Technical Electives:

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.

		Units
99-101	Core@CMU	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
38-430	ENGAGE in Wellness: Looking Forward	1
38-304	Reading and Writing Science ⁵	6
xx-xxx	Cultural/Global Understanding Elective ⁶	9
xx-xxx	Four Non-Technical Electives ⁷	36

Total Non-Technical Units 75

[5] Refer to the Mellon College of Science's Science and Society list for alternate courses that will fulfill this requirement. Placement credit may not be used.

[6] 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.

[7] 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.

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.

First Year

		Units
Fall		
99-101	Core@CMU	3
38-101	EUREKA!: Discovery and Its Impact	6
33-121	Physics I for Science Students	12
or 33-151	Matter and Interactions I	
Corequisite for	33-121 is 21-120 & for 33-151 is 21-122	
21-120	Differential and Integral Calculus	10
or 21-122	Integration and Approximation	
xx-xxx	MCS/Physics Technical Core Requirement 1 of 3	9-12
76-101	Interpretation and Argument	9
or 76-100	Reading and Writing in an Academic Context	

First-Year Fall Units 49-52

		Units
Spring		
33-142	Physics II for Engineering and Physics Students	12
or 33-152	Matter and Interactions II	
Corequisite for	33-142 is 21-122 & for 33-152 is 21-259	
33-104	Experimental Physics	9
21-122	Integration and Approximation	10
or 21-259	Calculus in Three Dimensions	
xx-xxx	MCS/Physics Technical Core Requirement 2 of 3	9-12
xx-xxx	Non-Technical Elective 1 of 4	9

First-Year Spring Units 49-52

Sophomore Year

		Units
Fall		
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 (if not already taken)	10
xx-xxx	MCS/Physics Technical Core Requirement 3 of 3	9-12
xx-xxx	Cultural/Global Understanding Elective	9-12

Sophomore Fall Units 50-56

		Units
Spring		
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

		Units
Fall		
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

		Units
Spring		
33-302	Physics Upperclass Colloquium II	1
38-304	Reading and Writing Science (Science and Society)	6
33-340	Modern Physics Laboratory	10
38-110	ENGAGE in Service	1
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 45-54

Sample Schedule (No Track)

BEGINNING FALL 2015 AND BEYOND

Senior Year

Fall	Units
38-430 ENGAGE in Wellness: Looking Forward	1
38-220 ENGAGE in the Arts	2
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 48-63

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 up to 80 units of free electives, it is feasible for students to obtain, for example, an additional 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 Director of 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.

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	
Corequisite for 33-121 is 21-120	
33-142 Physics II for Engineering and Physics Students	12
or 33-152 Matter and Interactions II	
Corequisite for 33-142 is 21-122	
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 Physics 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.

21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-259	Calculus in Three Dimensions	10
Total Mathematics Core Units		30

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

03-121	Modern Biology ⁹	9
09-105	Introduction to Modern Chemistry ¹⁰	10
15-112	Fundamentals of Programming and Computer Science ¹¹	10-12
or 15-110	Principles of Computing	
Total Technical Core Units		29-31

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

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

[11] If 15-112 is satisfied through placement credit, students 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.

33-xxx	Two Qualifying Physics Electives	18-24
Total Technical Electives		18-24

Non-Technical Electives:

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.

99-101	Core@CMU	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
38-304	Reading and Writing Science ¹²	6
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Cultural/Global Understanding Elective ¹³	9
xx-xxx	Four Non-Technical Electives ¹⁴	36
Total Non-Technical Elective Units		75

[12] Refer to the Mellon College of Science's Science and Society list for alternate courses that will fulfill this requirement. Placement credit may not be used.

[13] 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.

[14] 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.

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.

xx-xxx	Free Electives ¹⁵	Units 72-80
Total Free Electives		72-80

[15] 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.

	Units
33-224 Stars, Galaxies and the Universe	9
33-226 Physics of Energy	9
33-353 Intermediate Optics	12
33-355 Nanoscience and Nanotechnology	9
33-441 Introduction to Biophysics	10
33-444 Introduction to Nuclear and Particle Physics	9
33-448 Introduction to Solid State Physics	9
33-466 Extragalactic Astrophysics and Cosmology	9
33-467 Astrophysics of Stars and the Galaxy	9
33-650 General Relativity	9

Total Physics Breadth Elective Units 9-12

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, enabling 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) ¹⁶	9
33-115 Physics for Future Presidents (B.A. and Minor only) ¹⁶	9
33-120 Science and Science Fiction (B.A. and Minor only) ¹⁶	9
33-224 Stars, Galaxies and the Universe	9
33-226 Physics of Energy	9
33-241 Introduction to Computational Physics	9
33-332 Physical Mechanics II	10
33-339 Intermediate Electricity and Magnetism II	10
33-342 Thermal Physics II	10
33-350 Undergraduate Research ¹⁷	Var.
33-353 Intermediate Optics (Alt. Fall - F22, F24)	12
33-355 Nanoscience and Nanotechnology (Alt. Fall - F23, F25)	9
33-441 Introduction to Biophysics	10
33-444 Introduction to Nuclear and Particle Physics	9
33-445 Advanced Quantum Physics I	9
33-446 Advanced Quantum Physics II	9
33-448 Introduction to Solid State Physics	9
33-451 Senior Research ¹⁷	Var.
33-456 Advanced Computational Physics	9
33-466 Extragalactic Astrophysics and Cosmology	9
33-467 Astrophysics of Stars and the Galaxy	9
33-499 Supervised Reading ¹⁷	Var.
33-650 General Relativity	9

33-658 Quantum Computation and Quantum Information Theory	10
33-659 Quantum Hall Effect and Topological Insulators	12
33-7xx Physics Graduate Level Courses (see list below)	

Total Qualifying Physics Electives Units 27-37

[16] Only one of these three courses (33-114, 33-115, and 33-120) may be used for the B.A. These classes may not be used as Qualifying Physics Electives for the B.S.

[17] Only one of these three courses (33-350, 33-451, and 33-499) of 9 units may be used as a Qualifying Physics Elective. Any exceptions must be approved by the Director of Undergraduate Affairs.

Qualifying Physics Electives Recommended for Physics Graduate School

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

	Units
33-332 Physical Mechanics II	10
33-339 Intermediate Electricity and Magnetism II	10
33-445 Advanced Quantum Physics I	9
33-446 Advanced Quantum Physics II	9

Qualifying Physics Electives Recommended for Graduate School in Physics

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. **Undergraduate students require special permission of the instructor and the Director of Undergraduate Affairs to register for these classes.**

33-755 Quantum Mechanics I	12
33-756 Quantum Mechanics II	12
33-758 Quantum Computation and Quantum Information Theory	12
33-759 Introduction to Mathematical Physics I	12
33-761 Classical Electrodynamics I	12
33-762 Classical Electrodynamics II	12
33-765 Statistical Mechanics	12
33-767 Biophysics: From Basic Concepts to Current Research	12
33-769 Quantum Mechanics III: Many Body and Relativistic Systems	12
33-770 Field Theory I	12
33-771 Field Theory II	12
33-777 Introductory Astrophysics	12
33-778 Introduction to Cosmology	12
33-779 Introduction to Nuclear and Particle Physics	12
33-780 Nuclear and Particle Physics II	12
33-783 Solid State Physics	12

Physics Graduate Course Units Optional

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:

- No Track (p. 5)
- Applied Physics (p. 5)
- Astrophysics (p. 5)
- Biological Physics (p. 5)
- Chemical Physics (p. 6)
- Computational Physics (p. 6)
- Quantum Physics (p. 6)

The track descriptions and requirements are listed below.

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 Three Qualifying Physics Electives	27-37
21-2xx Mathematics Elective	9-10
xx-xxx Three STEM Electives ¹⁸	27-36
Total Technical Elective Units	72-95

[18] STEM electives are any courses in MCS (including Physics), SCS, Statistics, CIT, and others explicitly approved by the Director of Undergraduate Affairs.

Applied Physics 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 ¹⁹	9-12
xx-xxx Four Applied Physics/Laboratory Electives ¹⁹	36-48
33-350 Undergraduate Research ¹⁹	9
or 33-451 Senior Research	
21-2xx Mathematics Elective	9-10
Total Applied Track Elective Units	72-88

[19] The elective courses and research topic are decided after consultation with, and approval by, the Director of Undergraduate Affairs. Research must be completed in a single 9-unit block.

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 Undergraduate Research ²⁰	9
or 33-451 Senior Research	
21-2xx Mathematics Elective	9-10
xx-xxx Three STEM Electives	27-36
Total Astrophysics Track Elective Units	72-82

[20] The research topic must be approved by the Director of Undergraduate Affairs and must be completed in a single 9-unit block.

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 Director of Undergraduate Affairs to discuss interests and career goals and then choose electives that fulfill the requirements of the track.

The Biological Physics Track is excellent preparation for Medical School.

All courses suggested for medical school applicants can be completed within this track. Students interested in both the Biological Physics Track

and the pre-medical program should consult with both the Director of Undergraduate Affairs in the Physics Department and the Director of the Health Professions Program for help in planning their programs.

Program optimized for Biological Physical studies:

	Units
33-441 Introduction to Biophysics	10
or 03-439 Introduction to Biophysics	
33-xxx One Qualifying Physics Elective	9-12
21-2xx Mathematics Elective	9-10
03-231 Honors Biochemistry	9
09-217 Organic Chemistry I	9
09-218 Organic Chemistry II	9
03-xxx Two Biological Sciences Electives ²¹	18
Total Biological Physics Track Elective Units	73-77

[21] The elective courses in Biological Sciences are decided after consultation with, and approval by, the Director of Undergraduate Affairs.

Program optimized for Medical School preparation:

	Units
03-121 Modern Biology	9
or 03-151 Honors Modern Biology	
42-202 Physiology	9
03-124 Modern Biology Laboratory	9
or 03-206 Biomedical Engineering Laboratory	
or 03-343 Experimental Techniques in Molecular Biology	
09-105 Introduction to Modern Chemistry I	10
or 09-107 Honors Chemistry: Fundamentals, Concepts and Applications	
09-106 Modern Chemistry II	10
or 09-221 Laboratory I: Introduction to Chemical Analysis	
09-207 Techniques in Quantitative Analysis	9
or 09-221 Laboratory I: Introduction to Chemical Analysis	
09-217 Organic Chemistry I	9
or 09-219 Modern Organic Chemistry	
09-218 Organic Chemistry II	9
or 09-220 Modern Organic Chemistry II	
09-208 Techniques for Organic Synthesis and Analysis	9
or 09-222 Laboratory II: Organic Synthesis and Analysis	
33-121 Physics I for Science Students	12
or 33-141 Physics I for Engineering Students	
Corequisite for 33-121 is 21-120	
33-122 Physics II for Biological Sciences & Chemistry Students	9
or 33-142 Physics II for Engineering and Physics Students	
Corequisite for 33-122 is 21-122	
33-104 Experimental Physics	9
03-231 Honors Biochemistry	9
or 03-232 Biochemistry I	
21-111 Calculus I	10
or 21-120 Differential and Integral Calculus	
21-112 Calculus II	10
(A semester of statistics may substitute for a semester of calculus at many medical schools.) ¹⁴	
or 21-122 Integration and Approximation	
or 21-124 Calculus II for Biologists and Chemists	
36-200 Reasoning with Data	9
or 36-202 Methods for Statistics & Data Science	
or	
76-101 Interpretation and Argument	9
76-xxx English II Elective	9
85-xxx Psychology Elective (Intro to Psychology, Social Psychology)	9
xx-xxx Intro to Sociology (not offered at CMU)	9
Total Biological Physics Track Elective Units	187

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 Director of Undergraduate Affairs to discuss interests and career goals and then choose electives that fulfill the requirements of the track.

	Units
33-xxx One 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 Three Chemistry Electives ²²	27
Total Chemical Physics Track Elective Units	73-77

[22] The elective courses in Chemistry are decided after consultation with, and approval by, the Director of Undergraduate Affairs.

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 that are used in the analysis of physical problems in areas ranging from academia to Silicon Valley. The degree provides the student with a rigorous grounding in physics as well as in the foundations and practice of computational skills to address theoretical and applied problems in society. Flexibility in the degree requirements allows students to choose technical electives that prepare them for future careers in a range of emerging computational science fields including data science, artificial intelligence, and software development. Students who complete this track will also gain experience in the application of high-performance computing resources to a wide variety of problems.

	Units
33-241 Introduction to Computational Physics	9
33-456 Advanced Computational Physics	9
33-xxx One Physics Breadth Elective	9-12
33-xxx One Qualifying Physics Elective or xx-xxx Computational Science Elective ²³	9-12
21-127 Concepts of Mathematics	12
21-369 Numerical Methods	9-12
or 21-325 Probability	
or 36-225 Introduction to Probability Theory	
15-122 Principles of Imperative Computation	12
15-150 Principles of Functional Programming	12
Total Computational Physics Track Elective Units	81-90

[23] Selected in consultation with, and requires approval of, the Director of Undergraduate Affairs. Common choices outside qualifying physics electives include 10-301, 11-485, and 15-388, but other options may be approved.

Quantum Physics Track

In the early 20th century, the first quantum revolution led to a disruption of accepted physics paradigms and resulted in rapid innovation in science and technology. The development of the transistor, the laser, and the atomic clock, for example, allowed for innovations in computing, communications, and medical imaging that we now take for granted. The second quantum revolution, defined by the development and application of quantum materials and quantum computing, is poised to unleash another era of innovation in science and technology. The B.S. in Physics/Quantum Physics Track is designed for students who want to prepare for a career at the cutting-edge of this exciting field.

	Units
33-445 Advanced Quantum Physics I	9
33-446 Advanced Quantum Physics II	9
33-658 Quantum Computation and Quantum Information Theory	10

33-448 Introduction to Solid State Physics	9
or 33-444 Introduction to Nuclear and Particle Physics	
or 33-355 Nanoscience and Nanotechnology	
33-350 Undergraduate Research ²⁴	9
or 33-451 Senior Research	
21-2xx Mathematics Elective	9-10
xx-xxx Two STEM Electives	18-24
Total Quantum Track Elective Units	73-80

[24] The elective courses and research topic are decided after consultation with, and approval by, the Director of Undergraduate Affairs. Research must be completed in a single 9-unit block.

Additional Major or Dual Degree in Physics

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. Students interested in either option should contact Dr. Gillian Ryan, Director of Undergraduate Affairs, for assistance, and should have successfully completed at least one core physics course at Carnegie Mellon prior to applying for these options.

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	
Corequisite for 33-121 is 21-120	
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	10
Total Mathematics Core Units		30

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 Undergraduate Affairs, Mellon College of Science).

15-110	Principles of Computing	10-12
	or 15-112 Fundamentals of Programming and Computer Science	
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 may opt to complete the requirements as part of the Physics Tracks (p. 4) described in the B.S. in Physics section. Students interested in completing an additional major with a track should consult with the Director of Undergraduate Affairs.

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 Director of 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). Students are required to have successfully completed at least one physics course at Carnegie Mellon before declaring the minor, and should declare the minor no later than the add date of their final semester. Interested students should contact Dr. Gillian Ryan, Director of Undergraduate Affairs, and complete the minor declaration form (https://www.cmu.edu/mcs/undergrad/advising/forms/mcs_additional_major-minor.pdf) with her assistance.

33-121	Physics I for Science Students	12
	or 33-141 Physics I for Engineering Students	
	or 33-151 Matter and Interactions I	
Corequisite for 33-121 or 33-141 is 21-120 & for 33-151 is 21-122		
33-122	Physics II for Biological Sciences & Chemistry Students	12
	or 33-142 Physics II for Engineering and Physics Students	
	or 33-152 Matter and Interactions II	
Corequisite for 33-122 or 33-142 is 21-122 & for 33-152 is 21-259		
33-104	Experimental Physics	9
33-211	Physics III: Modern Essentials	10

33-xxx	Three Qualifying Physics Electives or Physics Core Electives ²⁵	27-36
Total Physics Minor Units		70-79

[25] The physics electives are decided after consultation with, and approval by, the Director of 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.

Transfer Credit Requests

Requests for transfer credit for undergraduate physics classes should be made through the student's home college to the Director of Undergraduate Affairs. Students should contact their departmental academic advisor for the transfer request process in their college. Requests should **not** be made from students directly to the Department of Physics. It is recommended that requests be placed before paying tuition for a class in case transfer credit is denied. Requests may take 1-2 weeks to be processed by the Department of Physics.

Criteria for Transfer

In assessing the suitability of courses for transfer credit, the Department of Physics will consider the following factors:

- The academic rigor of the course must be comparable to that offered at Carnegie Mellon University. This is usually assessed via the course prerequisites and corequisites, the textbook used, and the amount of time spent on topic areas. Completely online classes without in-person proctored examinations do not meet our standard for transfer credit.
- The mathematical rigor of a course must also be comparable to that for the CMU course for which a transfer is requested. For example, a class that has no math prerequisite is unlikely to transfer as a CMU class for which there is such a prerequisite, and algebra-based Physics I or Physics II classes will not be accepted for transfer as our calculus-based courses.
- The topic areas of a given class and time devoted to each topic should match to a degree of at least 80% those covered in the comparable physics course at Carnegie Mellon University, although this criterion alone is not sufficient to merit transfer. Classes that meet this criterion may still be denied transfer credit if key topics are found to be excluded or if the above mentioned requirements regarding rigor are not met.

Requirements for Transfer Requests

The Department of Physics requires all the following materials to determine if transfer is recommended:

- Name of course and its home institution
- Number of credits/units/contact hours per week
- Course syllabus
- Official catalog course description and list of topics covered in the course
- A list of all prerequisite and corequisite courses, and official catalog course descriptions of these courses
- Required textbook (name, author, and link to information about the text required)

Transfer requests that do not include all information above will not be recommended.

Faculty

JOHN ALISON, Associate Professor of Physics - Ph.D., University of Pennsylvania; Carnegie Mellon, 2018-

DAVID ANDERSON, Associate Teaching Professor of Physics - Ph.D., University of York (UK) ; Carnegie Mellon, 2008-

SHILADITYA BANERJEE, Associate Professor of Physics - Ph.D., Syracuse University; Carnegie Mellon, 2020-

KATELYN BREIVIK, Assistant Professor of Physics - Ph.D., Northwestern University; Carnegie Mellon, 2023-

ROY A. BRIERE, Professor of Physics - Ph.D., University of Chicago; Carnegie Mellon, 1999-

SHUBHAYU CHATTERJEE, Assistant Professor of Physics - Ph.D., Harvard University; Carnegie Mellon, 2023-

HAEL COLLINS, Assistant Teaching Professor of Physics - Ph.D., Harvard University; Carnegie Mellon, 2019-

MATTEO CREMONESI, Assistant Professor of Physics – Ph.D., Oxford University; Carnegie Mellon, 2022–

RUPERT CROFT, Professor of Physics – Ph.D., Oxford University; Carnegie Mellon, 2001–

MARKUS DESERNO, Professor of Physics; Director of Graduate Studies, Department of Physics – Ph.D., University of Mainz, Germany; Carnegie Mellon, 2007–

TIZIANA DI MATTEO, Professor of Physics – Ph.D., University of Cambridge; Carnegie Mellon, 2005–

VALENTINA DUTTA, Assistant Professor of Physics – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 2022–

SCOTT DODELSON, Professor of Physics – Ph.D., Columbia University; Carnegie Mellon, 2017–

RANDALL M. FEENSTRA, Professor of Physics – Ph.D., California Institute of Technology; Carnegie Mellon, 1995–

FRANK HEINRICH, Associate Research Professor of Physics – Ph.D., University of Leipzig; Carnegie Mellon, 2008–

BENJAMIN HUNT, Associate Professor of Physics – Ph.D., Cornell University; Carnegie Mellon, 2015–

TINA KAHNIASHVILI, Research Professor of Physics – Ph.D., Russian Academy of Sciences; Carnegie Mellon, 2010–

JYOTI KATOCH, Associate Professor of Physics – Ph.D., University of Central Florida; Carnegie Mellon, 2018–

VLADYSLAV KOZII, Assistant Professor of Physics – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 2022–

BARRY B. LUOKKALA, Teaching Professor of Physics – Ph.D., Carnegie Mellon University; Carnegie Mellon, 1988–

SARA A. MAJETICH, Professor of Physics – Ph.D., University of Georgia; Carnegie Mellon, 1990–

RACHEL MANDELBAUM, Professor of Physics; Interim Department Head, Department of Physics – Ph.D., Princeton University; Carnegie Mellon, 2011–

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–

BRENDAN MULLAN, Associate Teaching Professor; Director of Undergraduate Laboratories, Department of Physics – Ph.D., Pennsylvania State University; Carnegie Mellon, 2024–

ANTONELLA PALMESE, Assistant Professor of Physics – Ph.D., University College London; Carnegie Mellon, 2022–

DIANA S. PARNO, Associate Professor of Physics – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2017–

MANFRED PAULINI, Professor of Physics; Associate Dean, Mellon College of Science – Ph.D., University of Erlangen, Germany; Carnegie Mellon, 2000–

RICCARDO PENCO, Associate Professor of Physics – Ph.D., Syracuse University; Carnegie Mellon, 2018–

JEFFREY B. PETERSON, Professor of Physics – Ph.D., University of California, Berkeley; Carnegie Mellon, 1993–

RACHEL ROSEN, Associate Professor of Physics – Ph.D., New York University; Carnegie Mellon, 2023–

IRA Z. ROTHSTEIN, Professor of Physics – Ph.D., University of Maryland at College Park; Carnegie Mellon, 1997–

GILLIAN LYNN RYAN, Associate Teaching Professor of Physics; Director of Undergraduate Affairs, Department of Physics – Ph.D., Dalhousie University; Carnegie Mellon, 2020–

SUFEI SHI, Associate Professor of Physics – Ph.D., Cornell University; Carnegie Mellon, 2023–

FANGWEI SI, Assistant Professor of Physics – Ph.D., Johns Hopkins University; Carnegie Mellon, 2022–

SIMRANJEET SINGH, Assistant Professor of Physics – Ph.D., University of Central Florida; Carnegie Mellon, 2018–

GRIGORY TARNOPOLSKY, Assistant Professor of Physics – Ph.D., Princeton University; Carnegie Mellon, 2021–

HY TRAC, Associate Professor of Physics – Ph.D., University of Toronto; Carnegie Mellon, 2010–

MATTHEW WALKER, Associate Professor of Physics – Ph.D., University of Michigan; Carnegie Mellon, 2013–

MICHAEL WIDOM, Professor of Physics – Ph.D., University of Chicago; Carnegie Mellon, 1985–

Emeriti Faculty

LUC BERGER, Professor of Physics, Emeritus – Ph.D., University of Lausanne, Switzerland; Carnegie Mellon, 1960–

ARNOLD ENGLER, Professor of Physics, Emeritus – Ph.D., University of Berne, Switzerland; Carnegie Mellon, 1962–

THOMAS A. FERGUSON, Professor of Physics, Emeritus – 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–

GREGG B. FRANKLIN, Professor of Physics – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1984–

STEPHEN GAROFF, Professor of Physics – Ph.D., Harvard ; Carnegie Mellon, 1988–

FREDERICK J. GILMAN, Professor of Physics, Emeritus – Ph.D., Princeton University; Carnegie Mellon, 1995–

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–

LEONARD S. KISSLINGER, Professor of Physics, Emeritus – Ph.D., Indiana University; Carnegie Mellon, 1969–

GEORGE KLEIN, Associate Teaching Professor of Physics – Ph.D., New York University; Carnegie Mellon, 1993–

ROBERT W. KRAEMER, Professor of Physics, Emeritus – Ph.D., Johns Hopkins University; Carnegie Mellon, 1965–

MICHAEL J. LEVINE, Professor of Physics, Emeritus – Ph.D., California Institute of Technology; Carnegie Mellon, 1968–

LING-FONG LI, Professor of Physics, Emeritus – Ph.D., University of Pennsylvania; Carnegie Mellon, 1974–

MATHIAS LOSCHE, Professor of Physics – Ph.D., Technical University of Munich; Carnegie Mellon, 2005–

JOHN F. NAGLE, Professor of Physics, Emeritus – Ph.D., Yale University; Carnegie Mellon, 1967–

BRIAN P. QUINN, Professor of Physics, Emeritus – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1988–

JAMES S. RUSS, Professor of Physics, Emeritus – Ph.D., Princeton University; Carnegie Mellon, 1967–

REINHARD SCHUMACHER, Professor of Physics, Emeritus – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1987–

ROBERT F. SEKERKA, University Professor of Physics and Mathematics, Emeritus – Ph.D., Harvard ; Carnegie Mellon, 1969–

ROBERT M. SUTER, Professor of Physics, Emeritus – Ph.D., Clark University; Carnegie Mellon, 1981–

ROBERT H. SWENDSEN, Professor of Physics, Emeritus – Ph.D., University of Pennsylvania; Carnegie Mellon, 1984–

STEPHANIE TRISTRAM-NAGLE, Research Professor of Physics, Emerita – Ph.D., University of California, Berkeley; Carnegie Mellon, 1986–

NED S. VANDER VEN, Professor of Physics, Emeritus – Ph.D., Princeton University; Carnegie Mellon, 1961–

HELMUT VOGEL, Professor of Physics, Emeritus – Ph.D., University of Erlangen-Nuremberg; Carnegie Mellon, 1983–

Joint Appointments and Courtesy Appointments

SHELLEY ANNA, Professor of Chemical Engineering – Ph.D., Harvard University; Carnegie Mellon, 2003–

AXEL BRANDENBURG, Adjunct Professor of Physics – Ph.D., University of Helsinki; Carnegie Mellon, 2018–

SHIRLEY HO, Adjunct Associate Professor of Physics – Ph.D., Princeton University; Carnegie Mellon, 2012-

MOHAMMAD F. ISLAM, Associate Research Professor of Materials Science & Engineering – Ph.D., University of Pennsylvania; Carnegie Mellon, 2005-

NOA MAROM, Assistant Professor of Material Science and Engineering – Ph.D., Weizmann of Science; Carnegie Mellon, 2016-

MICHAEL E. MCHENRY, Professor of Materials Science and Engineering – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1989-

CARL RODRIGUEZ, Adjunct Professor of Physics – Ph.D., Northwestern University; Carnegie Mellon, 2023-

ANTHONY D. ROLLETT, Professor of Materials Science & Engineering – Ph.D., Drexel University; Carnegie Mellon, 1995-

MAREK SKOWRONSKI, Professor of Material Science and Engineering – Ph.D., Warsaw University; Carnegie Mellon, 1988-

VENKAT VISWANATHAN, Assistant Professor of Mechanical Engineering – Ph.D., Stanford University; Carnegie Mellon, 2014-

HUAIYING ZHANG, Assistant Professor of Biological Sciences – Ph.D., McGill University; Carnegie Mellon, 2022-

JIAN-GANG ZHU, Professor of Electrical and Computer Engineering – Ph.D., University of California San Diego; Carnegie Mellon, 1997-