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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
- 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 five 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	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
38-430	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.

Sample Schedule (No Track)

BEGINNING FALL 2015 AND BEYOND

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	
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**

Spring		Units
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

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 (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**

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
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**

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	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	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

		Units
03-121	Modern Biology [9]	9
09-105	Introduction to Modern Chemistry I [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.

		Units
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.

		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
38-304	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.

		Units
xx-xxx	Free Electives [15]	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. Certain courses are offered only in alternate years, as indicated.

		Units
33-224	Stars, Galaxies and the Universe	9
33-226	Physics of Energy	9
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
33-448	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, 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) [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 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.**

		Units
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. 4)
- Applied Physics (p. 5)
- Astrophysics (p. 5)
- Biological Physics (p. 5)
- Chemical Physics (p. 5)
- Computational 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 or 33-451	Undergraduate Research [19] / Senior Research	9
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 or 33-451	Undergraduate Research [20] / Senior Research	9
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 or 03-439	Introduction to Biophysics / Introduction to Biophysics	10
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 or 03-151	Modern Biology / Honors Modern Biology	9
42-202	Physiology	9
03-124 or 03-206 or 03-343	Modern Biology Laboratory / Biomedical Engineering Laboratory / Experimental Techniques in Molecular Biology	9
09-105 or 09-107	Introduction to Modern Chemistry I / Honors Chemistry: Fundamentals, Concepts and Applications	10
09-106 or 09-221	Modern Chemistry II / Laboratory I: Introduction to Chemical Analysis	10
09-207 or 09-221	Techniques in Quantitative Analysis / Laboratory I: Introduction to Chemical Analysis	9
09-217 or 09-219	Organic Chemistry I / Modern Organic Chemistry	9
09-218 or 09-220	Organic Chemistry II / Modern Organic Chemistry II	9
09-208 or 09-222	Techniques for Organic Synthesis and Analysis / Laboratory II: Organic Synthesis and Analysis	9
33-121 or 33-141	Physics I for Science Students / Physics I for Engineering Students	12
Corequisite for 33-121 is 21-120		
33-122 or 33-142	Physics II for Biological Sciences & Chemistry Students / Physics II for Engineering and Physics Students	9
Corequisite for 33-122 is 21-122		
33-100	Basic Experimental Physics	6
03-231 or 03-232	Honors Biochemistry / Biochemistry I	9
21-111 or 21-120	Calculus I / Differential and Integral Calculus	10
21-112	Calculus II (A semester of statistics may substitute for a semester of calculus at many medical schools.) [14]	10
or 21-122	Integration and Approximation	
or 21-124	Calculus II for Biologists and Chemists	
36-200 or 36-202 or 36-247	Reasoning with Data / Methods for Statistics & Data Science / Statistics for Lab Sciences	9
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		**184**

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.

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.

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).

		Units
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.

		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 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).

		Units
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 [24]	27-36
Total Physics Minor Units		**70-79**

[24] 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. Students should contact their departmental academic advisor for the transfer request process in their college. 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 quality of the institution and its physics program, the course prerequisites and corequisites, the textbook used, and the amount of time spent on topic areas. Only courses from semester-based institutions will be considered for transfer a one-to-one basis. In general, the rate of approval is significantly higher for four-year institutions with science majors as opposed to community colleges. Completely online classes with no proctored examination 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 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, Assistant 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–

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

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

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

JYOTI KATOCH, Assistant Professor or 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; Director of Undergraduate Laboratories, Department 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 – 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–

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, Assistant 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–

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

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–

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–