Molecular Biophysics and Biochemistry

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The programs offered by the Department of Molecular Biophysics and Biochemistry are planned for students interested in the molecular and chemical basis of biological processes and are well suited to students hoping to attend medical school or pursue graduate studies in biochemistry, molecular biology, genetics, or biophysics. The B.S. major, designed for those with a strong commitment to research, provides an intensive introduction to laboratory techniques in biochemistry and biophysics. Students in this program usually carry out research projects in faculty laboratories during their junior and senior years. The B.A. major provides the intellectual discipline of biochemistry and biophysics for students who also wish to have sufficient time to pursue in-depth studies outside the major or who are interested in molecular biology as a liberal education; they too may engage in research during their junior and senior years.

PREREQUISITES
The basic science courses required of all majors include four half-term units of foundational biology (BIOL 101, 102, 103, 104); a two-term lecture sequence in general chemistry with its associated laboratories; a first term course in organic chemistry with its associated laboratory; and two terms of calculus (MATH 112 and 116). The prerequisites in biology, chemistry, and mathematics may be satisfied by scores on Advanced Placement tests or placement examinations sufficient to earn acceleration credits in the particular subjects, even if the student does not choose to accelerate.

REQUIREMENTS OF THE MAJOR

B.S. degree program Thirteen courses are required beyond the prerequisites: a second term of organic chemistry with its associated laboratory; two term courses in physics numbered PHYS 170 or higher; one term of physical chemistry; MB&B 251L, 300, 301, 302, and 490; two additional upper-level MB&B electives, one of which must not be a laboratory or independent research course; one quantitative reasoning elective (e.g., MATH 120 or above, S&DS 105 or 230 or above, CPSC 201 or above, or ENAS 130 or above); and one elective in the natural sciences at a level higher than required in the prerequisites. Students choose the elective courses in consultation with a faculty adviser (see below). Only two course credits of MB&B 470, 471, and 478, 479 may count toward these electives. Students may substitute CHEM 333 for MB&B 302. The physics requirement may be satisfied by an Advanced Placement test score sufficient to earn acceleration credit in that subject. The quantitative reasoning requirement may not be fulfilled by Advanced Placement test scores.

B.A. degree program Eleven courses are required beyond the prerequisites: a second term of organic chemistry with its associated laboratory; two term courses in physics numbered PHYS 170 or higher; one term of physical chemistry; MB&B 251L, 300, 301, 302, and 490; one additional upper-level MB&B elective; and one quantitative reasoning elective (e.g., MATH 120 or above, S&DS 105 or 230 or above, CPSC 201 or above, or ENAS 130 or above). Students choose the elective courses in consultation with a faculty adviser (see below). Students may substitute CHEM 333 for MB&B 302. The physics requirement may be satisfied by an Advanced Placement test score sufficient to earn acceleration credit in that subject. The quantitative reasoning requirement may not be fulfilled by Advanced Placement test scores.

Credit/D/Fail Courses taken Credit/D/Fail may not be counted toward the requirements of the major.

Roadmap See visual roadmap of the requirements.

SENIOR REQUIREMENT
The senior requirement for both the B.S. and the B.A. is fulfilled by successful completion of the senior project, MB&B 490. Students enrolled in this course prepare a written report and make an oral presentation of a literature project. Students meet with faculty members in charge of the colloquium during the first two weeks of the spring term to agree on a topic and an approach. It is appropriate for students who took research for credit earlier in their training to write on their research topic. It is inappropriate for students to submit a revised version of a past research report or to resubmit a literature paper prepared for another course. The literature project for the senior requirement should be original work approved by the faculty member overseeing the senior colloquium.

The written report is expected to be 15–25 pages in length (double-spaced, twelve-point font, exclusive of figures). A first draft of the paper is due two weeks prior to the date of the oral presentation. Faculty in charge of the program will review the draft and return it to the student with suggestions. A final draft of the paper is due the first day of the reading period in the student’s final term.

Students make a fifteen-minute oral presentation during the last three weeks of their final term in a general scientific forum open to the public. Other students in the series are expected to attend all presentations.

ADVISING

Recommended courses All B.S. majors are encouraged to include MB&B 470 or 471 among their MB&B electives. Declared MB&B majors may take up to two credits of these independent research courses for a letter grade. The prerequisites in either general or organic chemistry should be taken in the first year.

Students with a strong interest in biophysics, including those planning to attend graduate school, are strongly encouraged to take courses beyond the basic requirements of the major. Such students are advised to take mathematics through differential equations.
Molecular Biophysics and Biochemistry

(ENAS 194, MATH 246, or PHYS 301) and a full year of physical chemistry (CHEM 328 or 332, and 333). In place of one term of biophysics (MB&B 302) they may elect a full year of upper-level biophysics (MB&B 420 and graduate courses in optical spectroscopy and macromolecular interactions). Such revisions to the basic curriculum must be made in consultation with the faculty adviser.

Graduate work Graduate courses in molecular biophysics and biochemistry, biology, and the biomedical sciences that may be of interest to undergraduates are listed in the Graduate School bulletin, and many are posted on the Biological and Biomedical Sciences website. Additional information is available from the DUSes and the director of graduate studies. Undergraduates with an appropriate background may enroll with the permission of the director of graduate studies and the instructor.

Typical programs Programs with the minimal number of science courses required of B.A. and B.S. majors are shown below. Students whose scores on the Advanced Placement tests make them eligible for advanced courses are urged to replace the elementary science courses with more advanced ones in their first year, and to complete the required biochemistry and physics courses by the end of their sophomore and junior years, respectively. Students are permitted to take the biochemistry sequence (MB&B 300, 301) after one term of organic chemistry (CHEM 220).

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<tr>
<th>First-Year</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
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<tr>
<td>BIOL 101, 102, 103, 104</td>
<td>CHEM 220, 221, 222L, 223L</td>
<td>MB&amp;B 300, 301, 251L</td>
<td>CHEM 328</td>
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<td>CHEM 161, 165, 134L, 136L</td>
<td>MATH 112, 116</td>
<td>One quantitative reasoning elective</td>
<td>MB&amp;B 302</td>
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<td>PHYS 180, 181</td>
<td>One MB&amp;B elective</td>
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<td>And, for B.S. major: One science elective and a second MB&amp;B elective</td>
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<td>MB&amp;B 490</td>
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Combined B.S./M.S. degree program Exceptionally able and well-prepared students may complete a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. See Academic Regulations, section K, Special Arrangements, "Simultaneous Award of the Bachelor's and Master's Degrees." Interested students should consult the DUS prior to the sixth term of enrollment for specific requirements in Molecular Biophysics and Biochemistry.

MB&B faculty advisory system Two MB&B faculty serve as academic advisers for each class year. Students may choose either of the advisers as listed for their class year and maintain an advising relationship throughout their studies. The advisers are apprised of curriculum-related details for each year and are authorized to sign schedules. Members acting as faculty advisers are:

Class of 2021:
- W. Gilbert, C-127 SHM (785-4857)
- A. Miranker, 313 BASS (432-8954)

Class of 2022:
- C. Paulsen, 234 BASS (432-5342)
- M. Koelle, CE28A SHM (737-5808)

Class of 2023:
- L. Kabche, TBD
- M. Simon, 220 BASS (737-3274)

Class of 2024:
- TBD

REQUIREMENTS OF THE MAJOR

Prerequisites B.S. and B.A. — BIOL 101, 102, 103, and 104; a two-term lecture sequence in general chem, with labs, and 1 term of organic chem with lab; MATH 112, 116

Number of courses B.S. — 13 term courses beyond prereqs, incl senior req; B.A. — 11 term courses beyond prereqs, incl senior req

Specific courses required B.S. and B.A. — MB&B 251L, 300, 301, 302

Distribution of courses B.S. — a second term of organic chem with lab; 1 term of physical chem; 2 terms of PHYS 170 or above; 2 addtl upper-level MB&B electives, 1 quantitative reasoning elective, and 1 natural science elective, all as specified; B.A. — a second term of organic chem with lab; 1 term of physical chem; 2 terms of PHYS 170 or above; 1 addtl upper-level MB&B elective and 1 quantitative reasoning elective, as specified

Substitution permitted CHEM 333 for MB&B 302

Senior requirement Senior project (MB&B 490)

The B.A. and B.S. degrees offered by the Department of Molecular Biophysics and Biochemistry (MB&B) are for students interested not just in what life is, but also in how it works. MB&B students seek to understand life at a mechanistic level by studying how the complex molecules found in living organisms create structures, carry out chemistry, and store and utilize information to generate the remarkable properties of living organisms. Biochemistry is the discipline that identifies and studies the molecules and chemical reactions in biological organisms. Molecular biophysics uses the methods of physics to study how these molecules work by determining their three-dimensional structures and mechanisms of action. For example, biochemistry was used to discover DNA and the fact that it
carries genetic information, while biophysics was used to discover its double-helix structure. The MB&B major is well suited to students planning to attend medical school or to pursue graduate studies and a career in biomedical research.

First years interested in the MB&B major should start their scientific studies at Yale by taking course work in chemistry and biology. Students should enroll in the most advanced chemistry courses for which they are eligible, and either in fall or spring term begin the four half-term, half-credit introductory biology courses prerequisite to all majors in the biological sciences. Information about the Chemistry placement process can be found on the department website.

The following program is recommended for the first year:

Select one of the following sequences:

Option 1:
- CHEM 161 and CHEM 134L
- CHEM 165 and CHEM 136L

Option 2:
- CHEM 163 and CHEM 134L
- CHEM 167 and CHEM 136L

And in fall or spring term, begin the following sequence of courses:
- BIOL 101
- BIOL 102
- BIOL 103
- BIOL 104

The single most important thing first-year students can do to prepare for the MB&B major is to take the most advanced chemistry course for which they qualify. If eligible, first years are urged to begin study with Comprehensive University Chemistry, and with the associated laboratories. Beginning organic chemistry as a first year allows a student to start course work in biochemistry in the sophomore year, and also allows a wider choice of advanced science electives in the junior and senior years. An organic chemistry series (CHEM 174 and 175) is offered specifically for first years and is popular with our majors.

First-year students are urged to contact the director of undergraduate studies (DUS).

FACULTY OF THE DEPARTMENT OF MOLECULAR BIOPHYSICS AND BIOCHEMISTRY

Professors  †Karen Anderson, Susan Baserga, †Ronald Breaker, †Gary Brudvig, †Sandy Chang, Enrique De La Cruz, †Daniel DiMaio, Donald Engelman, Alan Garen, Mark Gerstein, Nigel Grindley (Emeritus), †Sharon Hammes-Schiffer, Mark Hochstrasser, Jonathon Howard, Michael Koelle, Anthony Koleske, William Konigsberg, †Mark Lemmon, Peter Lengyel (Emeritus), †Patrick Loria, †L. George Miller, Andrew Miranker, †Peter Moore (Emeritus), Karla Neugebauer, †Thomas Pollard, †Karen Reinisch, †David Schatz, Robert Schultman (Emeritus), †Frederick Sigworth, Dieter Söll, Mark Solomon, Joan Steitz, Scott Strobel, Yong Xiong

Associate Professors  Julien Berro, †Titus Boggon, Wendy Gilbert, Christian Schlieker, Matthew Simon, Chuck Sindelar, †Shervin Takyar, †Yongli Zhang

Assistant Professors  Franziska Bleichert, Lilian Kabeche, †Erdem Karatekin, Nikhil Malvankar, †Wei Mi, Candice Paulsen, †Sarah Slavoff, Kai Zhang

Adjunct Professors  Kenneth Williams, Carl Zimmer

Lecturer  Aruna Pawashe

†A joint appointment with primary affiliation in another department.

Courses

* MB&B 050b, Topics in Cancer Biology  Sandy Chang
Introduction to cancer as a genetic disease, with a focus on major discoveries in cancer biology that offer mechanistic insights into the disease process. A brief history of cancer; influence of the genomic revolution on cancer diagnostics; molecular defects underlying specific cancers; current and future cancer therapeutics. Patient case studies highlight specific molecular pathways and treatment strategies. Enrollment limited to first-year students with a strong background in biology and/or chemistry, typically demonstrated by a score of 5 on Advanced Placement examinations. Preregistration required; see under First-Year Seminar Program.  WR, SC

* MB&B 099b / MCDB 099b / MENG 099b / PHYS 099b, Introduction to Research Methods in Physics and Biology: Preparing for a First Research Experience  Simon Mochrie, Andrew Miranker, Corey O’Hern, and Megan King
Spanning both the classroom and laboratory, this seminar course provides an immersive introduction to scientific research. Students build practical laboratory skills, computational competency, and begin to build fluency in the structures and modes of communication.
that define modern research. The course also facilitates identification of a laboratory mentor and devising a research proposal (with mentorship) for competitive summer research fellowship applications. This class is open to first-year students, interested in any STEM major, who have no prior research experience. This course does not count toward major requirements. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program.

**MRRB 105a or b / MCDB 105a or b, Biology, the World, and Us** Staff
Biological concepts taught in context of current societal issues, such as emerging diseases, genetically modified organisms, green energy, and the human brain and its disorders. Emphasis on biological literacy to enable students to evaluate scientific arguments. SC

* MB&B 107b / EDST 107b / PHYS 107b, Being Human in STEM  Mark Hochstrasser
A collaboratively-designed, project-oriented course that seeks to examine, understand, and disseminate how diversity of gender, race, religion, sexuality, economic circumstances, etc. shape the STEM experience at Yale and nationally, and that seeks to formulate and implement solutions to issues that are identified. Study of relevant peer-reviewed literature and popular-press articles. Implementation of a questionnaire and interviews of STEM participants at Yale. Creation of role-play scenarios for provoking discussions and raising awareness. Design and implementation of group interventions. SC

[ MB&B 110, Current Issues in Biological Science ]

* MB&B 200a or b / MCDB 300a or b, Biochemistry  Ronald Breaker and Staff
An introduction to the biochemistry of animals, plants, and microorganisms, emphasizing the relations of chemical principles and structure to the evolution and regulation of living systems. Prerequisites: BIOL 101 or equivalent performance on the corresponding biological sciences placement examination; one term of organic chemistry; or with permission of instructor. SC

[ MB&B 230, Rain Forest Expedition and Laboratory ]

* MB&B 251La or b / MCDB 301La or b, Laboratory for Biochemistry  Staff
An introduction to current experimental methods in molecular biology, biophysics, and biochemistry. Limited enrollment. Requires preregistration by e-mail to aruna.pawashe@yale.edu and andrew.miranker@yale.edu prior to the first week of classes. Please note: During the fall term, this course runs as two sections, Tuesday or Thursday from 1:15 p.m.-5:15 p.m., for the entire semester. During the spring term it meets once a week on Tuesdays. Prerequisite: BIOL 101. SC ½ Course cr

**MB&B 300a, Principles of Biochemistry I**  Matthew Simon, Michael Koelle, and Candie Paulsen
Discussion of the physical, structural, and functional properties of proteins, lipids, and carbohydrates, three major classes of molecules in living organisms. Energy metabolism and hormone signaling as examples of complex biological processes whose underlying mechanisms can be understood by identifying and analyzing the molecules responsible for these phenomena. After BIOL 101; after or concurrently with CHEM 175 (or CHEM 125) or 220 SC

**MB&B 301b, Principles of Biochemistry II**  Christian Schlieker, Joan Steitz, and Franziska Bleichert
Building on the principles of MB&B 300 through study of the chemistry and metabolism of DNA, RNA, and proteins. Critical thinking emphasized by exploration of experimental methods and data interpretation, from classic experiments in biochemistry and molecular biology through current approaches. Prerequisite: MB&B 300 or permission of instructor. SC

**MB&B 302b, Principles of Biophysics**  Enrique De La Cruz and Charles Sindelar
An introduction to the theoretical basis of biophysical concepts and approaches with selected examples and applications. Prerequisites: MB&B 300 and CHEM 328. SC

**MB&B 303a / BENG 230a / MCDB 303a / NSCI 324a, Modeling Biological Systems I**  Thierry Emonet, Damon Clark, and Joe Howard
Biological systems make sophisticated decisions at many levels. This course explores the molecular and computational underpinnings of how these decisions are made, with a focus on modeling static and dynamic processes in example biological systems. This course is aimed at biology students and teaches the analytic and computational methods needed to model genetic networks and protein signaling pathways. Students present and discuss original papers in class. They learn to model using MatLab in a series of in-class hackathons that illustrate the biological examples discussed in the lectures. Biological systems and processes that are modeled include: (i) gene expression, including the kinetics of RNA and protein synthesis and degradation; (ii) activators and repressors; (iii) the lysozyme/lysis switch of lambda phage; (iv) network motifs and how they shape response dynamics; (v) cell signaling, MAP kinase networks and cell fate decisions; and (vi) noise in gene expression. Prerequisites: MATH 115 or 116. BIOL 101-104; or with permission of instructors. This course also benefits students who have taken more advanced biology courses (e.g. MCDB 200, MCDB 310, MB&B 300/301). QR, SC

**MB&B 316b / BENG 406b / MCDB 316b / NSCI 326b, Modeling Biological Systems II**  Joe Howard, Thierry Emonet, and Jing Yan
Advanced topics related to dynamical processes in biological systems. Processes by which cells compute, count, tell time, oscillate, and generate spatial patterns. Time-dependent dynamics in regulatory, signal-transduction, and neuronal networks; fluctuations, growth, and form. Comparisons between models and experimental data. Dynamical models applied to neurons, neural systems, and cellular biophysical processes. Use of MATLAB to create models. Prerequisite: MCDB 330 or equivalent, or a 200-level biology course, or with permission of instructor. QR

**MRRB 420a, Macromolecular Structure and Biophysical Analysis**  Yong Xiong, Joe Howard, and Jack Zhang
Analysis of macromolecular architecture and its elucidation using modern methods of structural biology and biochemistry. Topics include architectural arrangements of proteins, RNA, and DNA; practical methods in structural analysis; and an introduction to diffraction and NMR. Prerequisites: MBB 301 and 302. SC
* MB&B 425a / MCDB 425a, Basic Concepts of Genetic Analysis  Jun Lu
The universal principles of genetic analysis in eukaryotes. Reading and analysis of primary papers that illustrate the best of genetic analysis in the study of various biological issues. Focus on the concepts and logic underlying modern genetic analysis. Prerequisite: MCDB 202 or pre-approval of instructor. sc

MB&B 435a, Quantitative Approaches in Biophysics and Biochemistry  Yong Xiong
An introduction to quantitative methods relevant to analysis and interpretation of biophysical and biochemical data. Topics include statistical testing, data presentation, and error analysis; introduction to mathematical modeling of biological dynamics; analysis of large datasets; and Fourier analysis in signal/image processing and macromolecular structural studies. Instruction in basic programming skills and data analysis using MATLAB; study of real data from MB&B research groups. Prerequisites: MATH 120 and MB&B 300 or equivalents, or with permission of instructors. QR, SC

MB&B 443b, Advanced Eukaryotic Molecular Biology  Mark Hochstrasser, Matthew Simon, Franziska Bleichert, and Wendy Gilbert
Selected topics in regulation of chromatin structure and remodeling, mRNA processing, mRNA stability, translation, protein degradation, DNA replication, DNA repair, site-specific DNA recombination, and somatic hypermutation. Prerequisites: MB&B 300 and 301, or permission of instructor. sc RP

* MB&B 445b, Methods and Logic in Molecular Biology  Wendy Gilbert, Mark Hochstrasser, and Christian Schlieker
An examination of fundamental concepts in molecular biology through analysis of landmark papers. Development of skills in reading the primary scientific literature and in critical thinking. Prerequisites: MB&B 300 and 301. sc RP

MB&B 449a, Medical Impact of Basic Science  Joan Steitz, I. George Miller, Daniel DiMaio, Franziska Bleichert, Sandy Chang, Karla Neugebauer, and Seyedtaghi Takyar
Examples of recent discoveries in basic science that have elucidated the molecular origins of disease or that have suggested new therapies for disease. Readings from the primary scientific and medical literature, with emphasis on developing the ability to read this literature critically. Prerequisites: MB&B 300 and 301 or equivalents, or permission of instructor. sc

MB&B 452b / MCDB 452b / S&DS 452b, Biomedical Data Science, Mining and Modeling  Mark Gerstein and Matthew Simon
Techniques in data mining and simulation applied to bioinformatics, the computational analysis of gene sequences, macromolecular structures, and functional genomics data on a large scale. Sequence alignment, comparative genomics and phylogenetics, biological databases, genetic analysis of protein structure, molecular-dynamics simulation, biological networks, microarray normalization, and machine-learning approaches to data integration. Prerequisites: MB&B 301 and MATH 115, or permission of instructor. sc

* MB&B 459b / ENGL 459b / EVST 215b, Writing about Science, Medicine, and the Environment  Carl Zimmer
Advanced non-fiction workshop in which students write about science, medicine, and the environment for a broad public audience. Students read exemplary work, ranging from newspaper articles to book excerpts, to learn how to translate complex subjects into compelling prose. Admission by permission of the instructor only. Applicants should email the instructor at carl@carlzimmer.com with the following information: 1. One or two samples of nonacademic, nonfiction writing. (No fiction or scientific papers, please.) Indicate the course or publication, if any, for which you wrote each sample. 2. A note in which you briefly describe your background (including writing experience and courses) and explain why you’d like to take the course. WR RP

* MB&B 460lb, Advanced Laboratory for Biochemistry  Andrew Miranker and Aruna Pawashe
This is a project-oriented course in which each student tackles a unique research problem of their own design. Students learn cutting-edge molecular evolution techniques to create a new DNA structure that can specifically recognize and bind whatever target material they choose. Useful and transferrable skills include biomolecular engineering and next generation DNA sequencing. Students learn from each other as they each report on their progress. The course is open to students interested in augmenting the research they are already doing or to students who simply prefer hands-on learning. Prerequisite: MB&B 251L or permission of the instructor. Some students may take this course concurrently with MB&B 251L if they have sufficient prior knowledge of organic chemistry, biochemistry, and basic biochemical lab techniques. sc ½ Course cr

* MB&B 470a and MB&B 471b, Research in Biochemistry and Biophysics for the Major  Jack Zhang
Individual laboratory projects under the supervision of a faculty member. Students must submit an enrollment form that specifies the research supervisor by the date that course schedules are due. Students are expected to commit at least ten hours per week to working in a laboratory. Written assignments include a research proposal, due near the beginning of the term, and a research report that summarizes experimental results, due before the beginning of the final examination period. Students receive a letter grade. Up to 2 credits of MB&B 470/471 may be counted toward the MB&B major requirements. Enrollment limited to MB&B majors. Prerequisite: MB&B 251L or permission of the instructor. sc

* MB&B 472a and MB&B 473b, Research in Biochemistry and Biophysics  Jack Zhang
Individual laboratory projects under the supervision of a faculty member. Students must submit an enrollment form that specifies the research supervisor by the date that course schedules are due. Students are expected to commit at least ten hours per week to working in a laboratory. Written assignments include a research proposal, due near the beginning of the term, and a research report that summarizes experimental results, due before the beginning of the final examination period. Students are graded pass/fail. Taken after students have completed two credits of MB&B 470 and 471. These courses do not count toward the major requirements. Prerequisites: MB&B 470, 471 and 251L or permission of the instructor. sc
* MB&B 478a and MB&B 479b, Intensive Research in Biochemistry and Biophysics  Jack Zhang
Individual laboratory projects under the supervision of a faculty member. Students must submit an enrollment form that specifies the research supervisor by the day that course schedules are due. Students are expected to commit at least twenty hours per week to working in a laboratory. Written assignments include a research proposal, due near the beginning of the term, and a research report that summarizes experimental results, due before the beginning of the final examination period. No more than two course credits count as electives toward the B.S. degree. Enrollment limited to senior MB&B majors. Prerequisite: MB&B 251L or 360L.  2 Course cr per term

* MB&B 490b, The Senior Project  Dieter Soll and Nikhil Malvankar
Colloquium for fulfillment of the senior requirement. The course involves a written and an oral presentation of a senior paper in an area of biochemistry or biophysics. The topic is selected in consultation with the faculty members in charge of the course.