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). BIOL 101, 102, chemistry, and mathematics prerequisites 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. BIOL 103 and 104 may be waived in consultation with an MB&B faculty advisor and permission of the director of undergraduate studies (DUS).

REQUIREMENTS OF THE MAJOR
The major requirements for the Class of 2024 and previous classes With approval from the DUS, the following changes to the major may be fulfilled by students who declared their major under previous requirements.

The following changes to the major requirements for the Class of 2025 and subsequent classes apply for the B.S. degree, the B.A. degree, and the B.S./M.S. degree.

B.S. degree program Thirteen course credits are required beyond the prerequisites: a second term of organic chemistry; two term courses in physics numbered PHYS 170 or higher; MB&B 275 or one term of physical chemistry followed by MB&B 302 or equivalent; MB&B 251L, 300, 301, 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); one elective in the natural sciences at a level higher than required in the prerequisites; and MB&B 268, a half-credit seminar taken concurrently with a humanities course elective. Only two course credits of independent research MB&B 470, 471, and 478, 479 may count toward these electives. The quantitative reasoning requirement may not be fulfilled by Advanced Placement test scores.

B.A. degree program Eleven course credits are required beyond the prerequisites: a second term of organic chemistry; two term courses in physics numbered PHYS 170 or higher; MB&B 275 or one term of physical chemistry; MB&B 251L, 300, 301, and 490; one additional upper-level MB&B elective; 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 MB&B 268, a half-credit seminar taken concurrently with a humanities course elective. Students choose the elective courses in consultation with a faculty adviser (see below). 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 (ENAS 194, MATH 246, or PHYS 301) and a full year of physical chemistry (CHEM 332 and 333). Thoughtful revisions to the basic curriculum can be made in consultation with the faculty adviser and are subject to approval by the DUS.

**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 online 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** Diverse pathways exist for navigating the B.A. and B.S. degrees with the minimum first-year requirements of BIOL 101, 102, 103 and 104, general chemistry with labs (e.g. CHEM 161, 165, 134L and 136L), and introductory calculus (e.g. MATH 112). For further examples, including the use of acceleration credits and DUS approved waivers, see the MB&B undergraduate handbook.

**Combined B.S./M.S. degree program** A very small number of students will be eligible to complete a six-year course of study within 8 terms of enrollment leading to the simultaneous award of the B.S. and M.S. degrees. 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. Members acting as faculty advisers are:

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

**Class of 2023:**
- L. Kabeche, West Campus
- M. Hochstrasser, 228 BASS (432-5101)

**Class of 2024:**
- F. Bleichert, YSB 345 (432-8411)
- A. Miraniker, 220 BASS (737-5274)

**Class of 2025:**
- 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 course credits beyond prereqs, incl senior req; B.A. — 11 term course credits beyond prereqs, incl senior req

**Specific courses required** B.S. and B.A. — MB&B 251L, 268, 300, 301

**Distribution of courses** B.S. — a second term of organic chem; MB&B 275 or one term of physical chemistry followed by MB&B 302 or equivalent; 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; 2 terms of PHYS 170 or above; MB&B 275 or one term of physical chemistry; 1 addtl upper-level MB&B elective and 1 quantitative reasoning elective, as specified

**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, †Patrick Loria, †I. George Miller, Andrew Miranker, †Peter Moore (Emeritus), Karla Neugebauer, †Thomas Pollard, †Karen Reinisch, †David Schatz, Robert Schulman (Emeritus), †Frederick Sigworth, Dieter Söll, Mark Solomon, Joan Steitz, Scott Strobel, Yong Xiong

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

Assistant Professors  Franziska Bleichert, †Luisa Escobar-Hoyos, Lilian Kabeche, †Erdem Karatekin, †Zachary Levine, 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.

View Courses

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 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
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 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 lysogeny/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: BIOL 101 or equivalent performance on the corresponding biological sciences placement examination; one term of organic chemistry; or with permission of instructor.

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.

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 aimed at biology students and teaches the analytic and computational methods needed to model genetic networks and protein signaling pathways 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 lysogeny/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 101-102, 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).
MB&B 361b / BENG 465b / MCDB 361b / N SCI 325b, Modeling Biological Systems II  Thierry Emonet, Joe Howard, and Damon Clark
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

* MB&B 364a / MCDB 364a, Light Microscopy: Techniques and Image Analysis  Joseph Wolenski and Scott Holley
A rigorous study of principles and pertinent modalities involved in modern light microscopy. The overall course learning objective is to develop competencies involving advanced light microscopy applications common to multidisciplinary research. Laboratory modules coupled with critical analysis of pertinent research papers cover all major light microscope methods—from the basics (principles of optics, image contrast, detector types, fluorescence, 1P and 2P excitation, widefield, confocal principle, TIRF), to more recent advances, including: superresolution, lightsheet, FLIM/FRET, motion analysis and force measurements. This course is capped at 8 students to promote interactions and ensure a favorable hands-on experience. Priority for enrollment is given to students who are planning on using these techniques in their independent research. Prerequisites: MCDB 205, PHYS 170/171 or above, either CHEM 161/165 or above; with CHEM 134L, 136L or permission from the instructor. SC

MB&B 365a, Biochemistry and Our Changing Climate  Karla Neugebauer
Climate change is impacting how cells and organisms grow and reproduce. Imagine the ocean spiking a fever: cold-blooded organisms of all shapes, sizes and complexities struggle to survive when water temperatures go up 2-4 degrees. Some organisms adapt to extremes, while others cannot. Predicted and observed changes in temperature, pH and salt concentration do and will affect many parameters of the living world, from the kinetics of chemical reactions and cellular signaling pathways to the accumulation of unforeseen chemicals in the environment, the appearance and dispersal of new diseases, and the development of new foods. In this course, we approach climate change from the molecular point of view, identifying how cells and organisms respond to changing environmental conditions. To embrace the concept of “one health” for all life on the planet, this course leverages biochemistry, cell biology, molecular biophysics, and genetics to develop an understanding of the impact of climate change on the living world. We consider the foundational knowledge that biochemistry can bring to the table as we meet the challenge of climate change. Prerequisites: MB&B 300, MB&B 301, MB&B 300, or permission of the instructor. SC

MB&B 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 425, 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 431b, Illuminating Biomolecular Mechanism with Structure  Charles Sindelar, Julien Berro, and Nikhil Malvankar
This class focuses on methods for observing biomolecular structure and dynamics on the atomic and near-atomic length scales. Upon completion of the class, students have a working understanding of the theory that underpin methods such as cryo-electron microscopy and optical spectroscopy. All methods introduced are anchored to fundamental processes in biology and to biomedical advances through guided discussion of ground-breaking studies in contemporary primary literature. Prerequisite: MB&B 275, 301, or permission of the instructor. Enrolled students should have an introductory level understanding of Fourier transforms, linear/matrix algebra and multivariate calculus, but note, portions of class time are used to review the small subset of relevant mathematics essential for this course. QR, SC

MB&B 435a, Quantitative Approaches in Biophysics and Biochemistry  Nikhil Malvankar and 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 Julien Berro
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, David Schatz, Daniel DiMaio, Franziska Bleichert, Sandy Chang, and Karla Neugebauer
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 352b, 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, geometric 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  Staff
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  Staff
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  Staff
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  Staff
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, Christian Schlieker, 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.