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.

The major for the Class of 2018 With DUS approval, the following changes to the requirement of the major may be fulfilled by students who declared their major under previous requirements.

The major for the Class of 2019 and subsequent classes For both degree programs, specific requirements are listed below.

PREREQUISITES

The basic science courses required of all majors include four half-term units of introductory biology (BIOL 101, 102, 103, 104); two general chemistry courses with laboratory (CHEM 161, 165, or CHEM 163, 167 [previously CHEM 112, 113, or CHEM 114, 115, or CHEM 118]; and CHEM 134L, 136L [previously CHEM 116L, 117L, or CHEM 119L]); a year course in organic chemistry with laboratory, (CHEM 174, 175 (previously CHEM 124, 125), or CHEM 220, 221 and CHEM 222L, 223L or CHEM 226L); one term of physical chemistry (CHEM 328); two terms of calculus (MATH 112 and 116); and one year of physics (PHYS 170, 171, or PHYS 180, 181, or PHYS 200, 201). Some of the prerequisites in biology, chemistry, mathematics, and physics 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 Nine courses are required beyond the prerequisites: MB&B 251L, 300, 301, 302, and 490; two additional upper-level MB&B electives, one of which must be a non-laboratory 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 quantitative reasoning requirement may not be fulfilled by Advanced Placement test scores.

B.A. degree program Seven courses are required beyond the prerequisites: 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 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.

SENIOR REQUIREMENT

The senior requirement for both the B.S. and the B.A. is fulfilled by successful completion of MB&B 490, The Senior Project. 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 freshman 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 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 bulletin of the Graduate School, and many are posted on the Biological and Biomedical Sciences Website. Additional information is available from the directors of undergraduate and 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).

First-Year	Sophomore	Junior	Senior
BIOL 101, 102, 103, 104	CHEM 220, 221, 222L, 223L	MB&B 300, 301, 251L	CHEM 328
CHEM 161, 165, 134L, 136L	MATH 112, 115	One quantitative reasoning elective	MB&B 302
		PHYS 180, 181	One MB&B elective
			And, for B.S. major: One science elective and a second MB&B elective
			MB&B 490

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 "Simultaneous Award of the Bachelor's and Master's Degrees" under Special Arrangements in the Academic Regulations. Interested students should consult the director of undergraduate studies prior to the sixth term of enrollment for specific requirements in Molecular Biophysics and Biochemistry.

MB&B faculty advisory system All undergraduates are assigned two MB&B advisers specifically appointed for their year, with the idea that undergraduates will have the opportunity to know at least one MB&B faculty member in addition to the DUS 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 2018:
K. Neugebauer, C 123 SHM (785-3322)
J. Berro, 309C JWG (737-3285, 432-5437)

Class of 2019:
J. Howard, 334A BASS (432-7245)
C. Schlieker, 236A BASS (432-5035)

Class of 2020:
E. De La Cruz, 336A BASS (432-5424)
P. Sung, C-130A SHM (785-4553)

Class of 2021:
W. Gilbert, C-127 SHM (785-4857)
M. Solomon, 218 BASS (436-9053)

REQUIREMENTS OF THE MAJOR

Prerequisites *B.S.* and *B.A.*—BIOL 101, 102, 103, and 104; CHEM 161, 165, or CHEM 163, 167 (or CHEM 112, 113, or CHEM 114, 115, or CHEM 118); CHEM 134L, 136L (or CHEM 116L, 117L, or CHEM 119L); CHEM 174, 175 (or CHEM 124, 125), or CHEM 220 221; and CHEM 222L, 223L or CHEM 226L; CHEM 328; MATH 112, 116; PHYS 170, 171, or PHYS 180, 181, or PHYS 200, 201
Number of courses *B.S.*—9 term courses beyond prereqs, incl senior req; *B.A.*—7 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.*—2 addtl MB&B electives, 1 quantitative reasoning elective, and 1 science elective, all as specified; *B.A.*—1 addtl 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)

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*), Mark Hochstrasser, Jonathon Howard, Anthony Koleske, William Konigsberg, †Mark Lemmon, Peter Lengyel (*Emeritus*), †Patrick Loria, †I. George Miller, Andrew Miranker, †Peter Moore

(*Emeritus*), Karla Neugebauer, †Thomas Pollard, Lynne Regan, †Karen Reinisch, †David Schatz, Robert Schulman (*Emeritus*), †Frederick Sigworth, Dieter Söll, Mark Solomon, Joan Steitz, Thomas Steitz, Scott Strobel, †William Summers (Emeritus), Patrick Sung, †Sandra Wolin

Associate Professors †Titus Boggon, Wendy Gilbert, Michael Koelle, Christian Schlieker, Matthew Simon, Chuck Sindelar, Yong Xiong

Assistant Professors Julien Berro, †Erdem Karatekin, Nikhil Malvankar, Candice Paulsen, †Sarah Slavoff, †Shervin Takyar

Adjunct Professors Kenneth Williams, Carl Zimmer

Lecturers †Robert Bazell, Aruna Pawashe

†A joint appointment with primary affiliation in another department.

Courses

*** MB&B 050a, 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 freshmen with a strong background in biology and/or chemistry, typically demonstrated by a score of 5 on Advanced Placement examinations. Preregistration required; see under Freshman Seminar Program. SC

MB&B 105a or b / MCDB 105a or b, An Issues Approach to Biology Staff
Biological concepts taught in context of current societal issues, such as emerging diseases, genetically modified organisms, green energy, stem cell research, and human reproductive technology. Emphasis on biological literacy to enable students to evaluate scientific arguments. SC

*** MB&B 107b / PHYS 107b, Being Human in STEM** Andrew Miranker and Lynne Regan
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. SO

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

*** MB&B 200a / MCDB 300a, Biochemistry** Ronald Breaker, Nicole Clay, and Donald Engelman
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 218La / HSAR 218La, Art and Biomolecular Recognition Laboratory** Andrew Miranker
Students create and execute original projects in materials science using biotechnological tools. Introduction to the technical examination of art, with analysis of works from Yale University Art Gallery collections; the chemical basis of artist's materials; applied techniques in biomolecular evolution. This course will meet one day a week on West Campus in Room A222B and one day a week on main campus. Prerequisite: college-level chemistry and/or biology, or the equivalent in advanced placement. Enrollment limited; preference to students not majoring in the biological sciences. Preregistration required; interested students should e-mail the instructor prior to the first week of classes. SC RP

[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 william.konigsberg@yale.edu prior to the first week of classes. After BIOL 101. SC ½ Course cr

MB&B 300a, Principles of Biochemistry I Matthew Simon and Michael Koelle
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 and Joan Steitz
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 Peter Moore
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 330a / MCDB 330a / NSCI 324a, Introduction to Dynamical Systems in Biology Thierry Emonet and Kathryn Miller-Jensen
Study of the analytic and computational skills needed to model genetic networks and protein signaling pathways. Review of basic biochemical concepts including chemical reactions, ligand binding to receptors, cooperativity, and Michaelis-Menten enzyme kinetics. Deep exploration of biological systems including: kinetics of RNA and protein synthesis and degradation; transcription activators and repressors; lyosogeny/lysis switch of lambda phage and the roles of cooperativity and feedback; network motifs such as feed-forward networks and how they shape response dynamics; cell signaling, MAP kinase networks and cell fate decisions; bacterial chemotaxis; and noise in gene expression and phenotypic variability. Students learn to model using MatLab in a series of in-class hackathons that illustrate biological examples discussed in lectures. Prerequisites: BIOL 101 and 102, and PHYS 170 and 171 or equivalents, or with permission of instructors. QR, SC

MB&B 361b / BENG 465b / MCDB 361b / NSCI 325b, Dynamical Systems in Biology Damon Clark, Thierry Emonet, and Jonathon Howard
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 420a, Macromolecular Structure and Biophysical Analysis Andrew Miranker, Yong Xiong, Jonathon Howard, Nikhil Malvankar, and Wendy Gilbert
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 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, Patrick Sung, Seyedtaghi Takyar, 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, Donald Engelman, 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, Thomas Steitz, I. George Miller, Andrew Miranker, David Schatz, 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, Biological Data Science, Mining and Modeling Mark Gerstein
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 459a / ENGL 459a / EVST 215a, 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** Alan Garen and Aruna Pawashe
An advanced laboratory in biochemistry, molecular biology, and biophysics. Students perform experiments on an individual basis that have unknown outcomes using techniques currently used in research labs. MB&B 251L or permission of the instructor. SC ½ Course cr

* **MB&B 470a and MB&B 471b, Research in Biochemistry and Biophysics for the Major** Karla Neugebauer
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. No more than two credits of MB&B 470/471 may be taken. These courses do count toward the degree 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** Karla Neugebauer
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 degree requirements. Prerequisites: MB&B 470, 471 and 251L or permission of the instructor. SC

* **MB&B 479b, Intensive Research in Biochemistry and Biophysics** Alan Garen
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. A required organizational meeting will be held at the beginning of each term. 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

* **MB&B 490b, The Senior Project** Mark Solomon, Dieter Söll, Thomas Steitz, and Matthew Simon
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.