

# 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

**The major for the Class of 2020 and previous classes** With DUS approval, the following changes to the requirements of the major may be fulfilled by students who declared their major under previous requirements.

**The major for the Class of 2021 and subsequent classes** Changes to the requirements of the major for both the B.S. degree program and B.A. degree program are described below.

**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 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 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 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** 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 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)

*Class of 2022:*

J. Berro, 230 BASS (432-5437)  
M. Koelle, CE28A SHM (737-5808)

## 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; two 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; two 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)

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, Michael Koelle, Anthony Koleske, William Konigsberg, †Mark Lemmon, Peter Lengyel (*Emeritus*), †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, Thomas Steitz, Scott Strobel, †William Summers (*Emeritus*), Patrick Sung

**Associate Professors** †Titus Boggon, Wendy Gilbert, 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

**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. SC

\* **MB&B 060a, Molecular Medicine** Sandy Chang

The main purpose of this course is to use benign and malignant hematological disorders to introduce fundamental concepts in molecular and cellular biology. Students emerge from this course with a firm understanding of the molecular pathways perturbed in various hematological disorders and the therapeutics currently used to exploit these pathways for disease treatment. Through lectures and reading of primary scientific literature, students learn about landmark discoveries in hematology and how these discoveries contribute to understanding of the normal hematopoietic system, and when perturbed, how diseases arise. Students also learn to (1) read primary scientific literature, (2) synthesize this material to present to the class and (3) learn how to write a short grant proposal. These skills are essential for any successful scientist or physician, and it's important to master them early. Enrollment limited to first-year students.

Preregistration required; see under First-Year Seminar Program. Prerequisite: score of 5 on the AP Biology exam or AP Chemistry exam. 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

\* **MB&B 107b / EDST 107b / PHYS 107b, Being Human in STEM** Helen Caines and Andrew Miranker

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 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 230, Rain Forest Expedition and Laboratory** ]

\* **MB&B 251La or b / MCDB 301La or b, Laboratory for Biochemistry** Aruna Pawashe and William Konigsberg

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. Meets for first half of the term. After BIOL 101. SC ½ Course cr

**MB&B 300a, Principles of Biochemistry I** Michael Koelle, Matthew Simon, Enrique De La Cruz, and Candice 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 and Karla Neugebauer

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 330a / MCDB 330a / NSCI 324a, Introduction to Dynamical Systems in Biology** Damon Clark, Kathryn Miller-Jensen, and Jonathon Howard

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; lysogeny/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** 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 and Yong Xiong

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** Julien Berro, Yong Xiong, and Jonathon Howard

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 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, Thomas Steitz, I. George Miller, David Schatz, Daniel DiMaio, Karla Neugebauer, and Wendy Gilbert

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 352, Biomedical 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](mailto: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** Aruna Pawashe and William Konigsberg

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** 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 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** 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 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 478a and 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. 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 Söll and Julien Berro

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.