

# Molecular Biophysics and Biochemistry

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Members of the Department of Molecular Biophysics and Biochemistry (MB&B) are united by a common view that processes in biology are understood when molecular, chemical, kinetic, and thermodynamic contributions to mechanisms have been elucidated. Correspondingly, our faculty and students are joined by a shared fascination with biochemistry, physical chemistry, structural biology, computation, spectroscopy, macromolecular engineering, imaging and the molecular basis of disease.

Three quarters of our graduates matriculate into PhD, MD, and MD/PhD programs. Other recent graduates have joined companies specializing in finance, management consulting, biotechnology, and pharma. Others have matriculated in law or business school and doctoral programs in the humanities. Still others have performed public service, entered secondary education, or joined the United States armed forces as officers.

## INTRODUCTORY COURSES

The basic introductory science courses suggested for all majors include a two-term lecture sequence in general chemistry with its associated laboratories (CHEM 1610, 1650, or CHEM 1630, 1670, and CHEM 1340L and 1360L); a one-term course in organic chemistry with its associated laboratory (CHEM 2200 or 1740 with CHEM 2220L); two terms of calculus (MATH 1120 and 1150 or MATH 1160); two half-term units of biochemistry, biophysics and cell biology (BIOL 1010, 1020). Some concentrations, described below, require additional introductory biology satisfied by (BIOL 1030, 1040).

## REQUIREMENTS OF THE MAJOR

The core elements of the major are biophysics, biochemistry, and science and society. The requirements beyond these core elements teach advanced concepts, and teach the technology and practical skills that enable scholarship in the discipline.

**B.A. Degree Program** The B.A. degree program requires a total of 9.5 course credits to include: 3 biophysics credits; 3 biochemistry credits, a half-credit for science and society; 1 credit to fulfill the practical skills requirement; 1 elective; and the senior requirement.

The *core Biophysics requirements* are two semesters of physics (PHYS 1700 and 1710 or higher) and one semester of biophysical chemistry (MB&B 2750 or CHEM 3320).

The *core Biochemistry requirements* include MB&B 3000 and 3010 (substitutions are not permitted), and CHEM 1750 or any 2000+ level Chemistry course.

The *Science and Society core requirement* is 0.5 credit (MB&B 2680 is recommended) and addresses the intersection of Molecular Biophysics & Biochemistry with human identity and society. Alternatives to MB&B 2680 are MB&B 1070, AFAM 1370, HSHM 2060, 241, 4060, 4240, 4750, 4810, HIST 1779, SOCY 1600, 1601, 3760, MCDB 3750, WGSS 2270, 4457. Students may petition for course substitutions.

The *Practical skills* requirement is fulfilled with one full-credit or two half-credit courses spread across two or three of the categories listed below. At least one half-credit must come from MB&B.

- Physics lab options include MB&B 1210L, 1220L, 1230L, 1240L, 4700 and 4710\*, PHYS 1650L, 1660L, CHEM 3550L, other 2000+ level lab courses with DUS approval.
- Biochemistry Lab options include MB&B 2510L, 4700 and 4710\*, CHEM 3550L, other 2000+ level lab courses with DUS approval.
- Critical Tools options include MB&B 4350, 4700 and 4710\*, S&DS 2380, CPSC 1001 and others with DUS approval.

\*MB&B 4700 and 4710 are research for credit courses. Above categorization is dependent on the research project. Up to two credits may be taken for a letter grade.

The *Elective course* should be a lecture or seminar MB&B course at the 2000+ level.

**B.S. Degree Program** The B.S. degree program requires a total of 12.5 course credits including the senior requirement. This program follows the requirements and policies of the B.A. degree program with the following additions.

For the *core Biophysics requirement*: one additional 3000+ course in physical sciences, mathematics, statistics or computer science

For the *Practical Skills requirement*: one additional credit for a total of two credits

For the *elective courses*: one additional 2000+ level seminar or lecture course in STEM

**Combined B.S./M.S. Degree Program** The B.S./M.S. degree program requires a total of 18.5 course credits including the senior requirement. See Academic Regulations, section L, Special Academic Arrangements, “Simultaneous Award of the Bachelor’s and Master’s Degrees.” Interested students should consult their academic adviser prior to the fifth term of enrollment for details and application requirements (due December 1 of the fifth semester). The B.S./M.S. program follows the requirements of the B.S. Degree program with the following additions.

For the *core Biophysics requirement*: one additional 3000+ course in thermodynamics, statistical mech, quantum and/or spectroscopy (CHEM 3320 is recommended). PHYS 1800 and 1810 in place of PHYS 1700 and 1710.

The *Practical Skills requirement* is replaced by one semester of MB&B 4700 or MB&B 4710 which must be completed by the end of the fifth semester.

For the *Elective course*, the single MB&B 2000+ seminar or lecture elective is replaced by two MB&B electives at 5000+ and four 5000+ electives in STEM.

#### CONCENTRATIONS

Concentrations in MB&B are sets of electives, curated by faculty, designed to focus attention on specific subfields of Molecular Biophysics and Biochemistry. Concentrations appear on a student’s official Yale transcript and are currently available in Biochemistry; Biophysics and Structural Biology; Chemical Biology; Computational Biology and Bioinformatics; Environment and Climate Change; and Medicine. Students must fulfill all major degree requirements,

earning a concentration is optional. For specific concentration requirements see the Concentrations section.

Electives taken for the major that meet the same criteria as requirements for a concentration may be used to fulfill both requirements. Placement exams and acceleration credits do not count towards completion of concentration-specific requirements. Instead, majors enroll in higher-level courses in the same concentration-specific category. Depending on the particular concentration and the choice of electives, concentrations add between zero and three additional credits to major requirements.

Some concentrations include research-for-credit courses or course-based undergraduate research experiences (CUREs) as a mechanism to fulfill a requirement. These courses must directly relate to the chosen concentration (broadly interpreted) and require DUS approval.

**Credit/D/Fail** No more than one course taken Credit/D/Fail may be applied toward the requirements of the major. This does count against Yale's limit of 6 total Credit/D/Fail courses. Qualifying courses must be 4000+ in MB&B, and 3000+ in any other STEM subject. For B.S./M.S. students, all required coursework must be taken for a letter grade.

**Outside credit** Courses taken at another institution or during an approved summer or term-time study abroad program may count toward the major requirements with DUS approval.

#### SENIOR REQUIREMENT

The senior requirement for both the B.S. and the B.A. is fulfilled by successful completion of a one credit senior essay. Students may enroll in MB&B 4900 and prepare a written report and make an oral presentation of a literature project or students may enroll in MB&B 4910 and write an essay that draws on laboratory research performed at Yale College. Students meet with faculty members in charge of the courses during the first two weeks of the term in which they are writing their essay, 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. The literature project for the senior requirement should be original work approved by the faculty member overseeing MB&B 4900.

The senior requirement for B.S./M.S. is completion of MB&B 5700 and 5701 taken during senior year.

#### ADVISING

Students are encouraged to declare their major long before completion of the introductory courses. This greatly improves academic advising. Changing majors at Yale does not require approval and is non-binding.

Students are assigned a member of MB&B faculty for academic advising as soon as they declare their major. Requests to change advisers should be sent to the registrar via email ([elizabeth.vellali@yale.edu](mailto:elizabeth.vellali@yale.edu)). Justification is not required nor is DUS approval.

**Course Substitutions** Students may petition their MB&B academic adviser for course substitutions by assembling the relevant syllabi and writing a short justification (less

than 300 words). Thoughtful requests in line with MB&Bs teaching goals are always welcome.

**DUS approvals:** DUS approvals for waivers, course substitutions, endorsement of petitions to the Committee on Honors and Academic Standing, applications to the B.S./M.S. program etc., are initiated by an email of support from student's assigned MB&B academic adviser. The academic adviser functions as the student's advocate on requests to the DUS with the MB&B registrar giving oversight and interfacing with the University registrar. One-on-one meetings by majors with their MB&B academic adviser during every registration period are logged. Failure to schedule meetings and missed meetings are factored into the DUS approval process.

**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 DUSs 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.

**Combined B.S./M.S. degree program** A very small number of students will be eligible to complete a four-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 L, Special Academic Arrangements, “Simultaneous Award of the Bachelor’s and Master’s Degrees.” Interested students should consult their academic adviser prior to the fifth term of enrollment.

**Sample schedules** Diverse pathways exist for navigating the B.A. and B.S. degrees. In general, students are strongly encouraged to complete General Chemistry (e.g. CHEM 1610, 1650, 1340L and 1360L), introductory calculus (e.g. MATH 1120) and introductory Biochemistry, Biophysics and Cell Biology (BIOL 1010, 1020) by the end of their first year. See the MB&B website for 4-year sample degree programs covering all six concentrations and for students who do not elect to pursue a concentration.

## SUMMARY OF MAJOR REQUIREMENTS

**Introductory courses** BIOL 1010 and 1020; 2 terms general chem with associated labs; 1 term organic chem with associated lab; 2 terms of calculus; BIOL 1030 and 1040 for some concentrations

**Number of courses** *B.A.*—9.5 course credits (incl senior project); *B.S.*—12.5 course credits (incl senior project)

**Distribution of courses** *B.A.*—3 biophysics credits to incl MB&B 2750 or CHEM 3320 and PHYS 1700 and 1710 or higher; 3 biochemistry credits to incl MB&B 3000, 3010, and CHEM 1750 or 2000+ Chem course; MB&B 2680, a half-credit for science and society or other course as approved by DUS; 1 credit practical skills course(s); and 1 MB&B elective 2000+ level or higher; *B.S.*—same reqs as for *B.A.* degree plus 1 addtl Practical Skills credit; 1 addtl 3000+ biophysics credit; and one addtl 2000+ credit in STEM

**Senior requirement** MB&B 4900 or MB&B 4910

## CONCENTRATIONS

### BIOCHEMISTRY CONCENTRATION

The concentration in Biochemistry is geared towards students seeking robust training in structure and function of nucleic acids and proteins in the context of life processes. Molecular length scale biochemistry is foundational to the mechanisms by which dynamic networks of molecular machines enable everything from cellular function to whole organism physiology. Failures in these networks are responsible for pathology in plants and animals, agriculture and medicine. MB&B majors interested in working in these fields directly after graduation, or who hope to pursue graduate studies including PhD and MD/PhD, are particularly encouraged to fulfill this concentration.

In addition to, or as part of, the degree requirements, the following courses are required:

*Genetics and Development and Ecology and Evolution:* BIOL 1030 and 1040

*Molecular, Cellular, or Organismal Biology:* MCDB 2050, MCDB 2020, or as approved by the DUS

*Research in Biochemistry:* MB&B 4700 or MB&B 4710 or course-based undergraduate research

*Advanced Chemical Biology lecture or seminar* (1 credit for B.A. degree and 2 credits for B.S. degree): 3000+ courses such as MB&B 3650, MB&B 3310, MB&B 4450, MB&B 4490, or MB&B 4430

### BIOPHYSICS AND STRUCTURAL BIOLOGY CONCENTRATION

This concentration is designed for students with strong interests in life processes on the molecular length scale. Majors aspiring to graduate studies in biophysics, molecular medicine, and biotechnology are particularly encouraged to fulfill this concentration.

Biophysics and Structural Biology are made possible by fundamental quantitative and physical tools such as linear algebra, Fourier analysis, x-ray diffraction, imaging, and optical spectroscopy to measure biomolecular dynamics and atomic resolution structure. Seminar courses applicable to this area focus on the basic biology enabled by exquisitely specific macromolecular interactions, the molecular basis of disease and drug-design.

In addition to, and/or as part of, the degree requirements, the following courses are required:

*Computer Science, Math, Statistics* (for B.A. degree): one from MATH 1200, MATH 2250, S&DS 1000+, or CPSC 1001

*Computer Science, Math, Statistics* (for B.S. degree): one from MATH 1200, MATH 2250, S&DS 2380, or CPSC 1001

*Biophysical Chemistry* (for B.S. degree): one from CHEM 3320 or any 3000+ elective in thermodynamics, statistical mech, quantum mechanics or spectroscopy

*Research in Biophysics and Structural Biology* (for both degrees): one from MB&B 4700, MB&B 4710, CHEM 3550L, or course-based undergraduate research

*Tools and Quantitative Analysis* (for B.S. degree): one 2000+ course with emphasis on measurement and/or modeling of energy, kinetics, or structure relevant to the molecular length scale, such as MB&B 3300, MB&B 4200, MB&B 4350, CHEM 3330, CHEM 4060, CHEM 4920, or as approved by the DUS

*Advanced Biophysics and Structural Biology lecture or seminar* (both degrees): one from MB&B 4200, MB&B 5200, or as approved by the DUS

#### CHEMICAL BIOLOGY CONCENTRATION

Chemical Biology leverages the tools and concepts of chemistry to understand and/or manipulate biological processes. Students interested in the MB&B concentration in Chemical Biology select electives from organic and inorganic chemistry as well as advanced courses in cell biology. Majors interested in additional studies in chemical biology, drug development, and/or biotechnology after graduation are particularly encouraged to fulfill this concentration.

In addition to, or as part of, the degree requirements, the following courses are required:

*Organic Chemistry* (both degrees): second semester of Organic Chemistry and accompanying half-credit lab

*Cell Biology and Chemistry* (for B.S. degree only): two 2000+ electives and one 3000+ elective in Chemistry or Cell Biology (at least one credit must cover cell biology or chemistry)

*Cell Biology* (for B.A. degree only): one 2000+ elective in cell-based biology

*Research in Chemical Biology* (both degrees): one from MB&B 4700, MB&B 4710, or MB&B 3640, or course-based undergraduate research

*Advanced Chemical Biology lecture or seminar* (both degrees): MB&B 4430 or CHEM 4190 or as approved by the DUS

#### COMPUTATIONAL BIOLOGY AND BIOINFORMATICS CONCENTRATION

This concentration is designed for students with strong interests in computer science, data science, statistics, and biology. Majors aspiring to graduate studies in computational biology, bioinformatics, medical informatics or biotechnology are particularly encouraged to fulfill this concentration.

In addition to, and/or as part of, the degree requirements, the following courses are required:

*Genetics and Evolutionary Biology* (B.A. degree): BIOL 1030 and 1040

*Genetics and Evolutionary Biology* (B.S. degree): one 2000+ elective in genetics, MCDB 2000, MCDB 2020, MCDB 3100, MB&B 3310

*Computer Science, Math, Statistics* (B.A. degree): CPSC 2010 and one S&DS 1000+ course

*Computer Science, Math, Statistics* (B.S. degree): CPSC 2230, CPSC 2010, and S&DS 2380 (CPSC 2230 may also be used to fulfill the 3000+ core biophysics elective requirement). Other courses may be substituted with permission of the DUS.

*Advanced Computational Biology & Bioinformatics* (both degrees): MB&B 3520 or CPSC 4530 or as approved by the DUS.

#### ENVIRONMENT AND CLIMATE CHANGE CONCENTRATION

This concentration is geared towards students seeking robust training in life processes as they affect, and are affected by the environment, human activity, and climate change. MB&B majors interested in working in these fields directly after graduation, or who hope to pursue graduate studies are particularly encouraged to fulfill this concentration.

In addition to, or as part of, the degree requirements, the following courses are required:

*Physical environmental science* (for B.S. degree): one credit 3000+ course from EVST 3620, EPS 3100, EPS 3230, EPS 3350, CHEM 3320, or CHEM 3330

*Environmental chemistry* (both degrees): one credit 2000+ course from EVST 3307, EPS 3100, CHEM 2520, or ENVE 4380. May be used to fulfill 2000+ elective requirement in chemistry.

*Math, statistics and/or computer science* (both degrees): one credit course from MATH 1200, MATH 1210, MATH 2220 or higher, S&DS 1000 or higher, or CPSC 1001 or higher. May be used to fulfill the practical skills requirement.

*Ecology and evolution* (both degrees): one credit 1000+ course from BIOL 1040, EEB 2225, or ANTH 2667. May be used to fulfill the 2000+ STEM requirement for the B.S. degree.

*Environmental Sciences* (both degrees): one credit 1000+ course from CENG 1200, EVST 2200, EVST 2550, EPS 1010, EPS 1250, EPS 1400, EPS 2320, or EPS 2610. May be used to fulfill 2000+ STEM requirement for B.S. degree.

*Advanced Environment Lecture or Seminar* (one credit for B.A. degree/two credits for B.S. degree): one or two credit courses from MB&B 3650, ENVE 4640, EVST 4005, EPS 3550, ENVE 4100, EPS 3230, ENVE 3600, ENVE 4380. MB&B 3650 may be used to fulfill 2000+ MB&B requirement for all degrees.

#### MEDICINE CONCENTRATION

This concentration is designed for students with strong interests in the molecular basis of physiology and disease. Majors aspiring to graduate studies in biomedical sciences, work in biotechnology, or medical school are particularly encouraged to fulfill this concentration.

In addition to, or as part of, the degree requirements, the following courses are required:

*Genetics and Development*: BIOL 1030 and 1040

*Organic Chemistry*: second term of organic chemistry (CHEM 1750 or 2210)

*Statistics*: Any introductory S&DS 1000+ or a 2000+ MATH course in linear algebra, probability, statistics or stochastic processes

*Psychology*: PSYC 1100 or higher

*Physics labs* (1 credit): MB&B 1210L, MB&B 1240L, PHYS 1650L, 1660L, MB&B 3640, or others as approved by the DUS (see below).

*Biomedical research* (total for 1 credit): MB&B 4700 or MB&B 4710, or course based undergraduate research including MB&B 2510L, MCDB 2910L, or others

*Advanced Seminar:* one

from MB&B 4450, MB&B 3520, MB&B 4490, MCDB 3150, MCDB 4500, or others as approved by the DUS.

#### FACULTY OF THE DEPARTMENT OF MOLECULAR BIOPHYSICS AND BIOCHEMISTRY

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**Assistant Professors** Franziska Bleichert, Allison Didychuk, †Luisa Escobar-Hoyos, Lilian Kabeche, †Wei Mi, Candice Paulsen, Kai Zhang

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†A joint appointment with primary affiliation in another department.