

# MOLECULAR, CELLULAR, AND DEVELOPMENTAL BIOLOGY

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The science of biology is extremely broad, ranging across the domains of molecules, cells, tissues and organs, organisms, and ecosystems. Moreover, biology explores questions of evolutionary history and the processes of evolutionary change, as well as the mechanisms by which cells, organisms, and ecosystems function. Students majoring in Molecular, Cellular, and Developmental Biology receive a thorough yet varied liberal education and preparation for professional careers in a diverse array of fields. Practical applications of biology include the development of biologicals and pharmaceuticals, the practice of medicine, and the pursuit of the scientific bases for understanding the development and function of biological systems.

Molecular, Cellular, and Developmental Biology (MCDB) offers programs for students wishing to concentrate on molecular and cellular biology and genetics, with applications to problems in cell and developmental biology, neurobiology, and various aspects of quantitative biology. Interdisciplinary opportunities are available within the major in the Biotechnology, Neurobiology, and Quantitative Biology tracks.

The MCDB major offers many opportunities for independent laboratory research. With approval, research can be conducted under the supervision of faculty members in any Yale department.

## PREREQUISITES

The foundational biology courses required of all MCDB majors are BIOL 101, 102, 103, and 104. All majors must also complete a course in mathematics numbered MATH 115 or higher or a statistics course taken at Yale.

For the B.A. degree, additional prerequisites are a two term lecture sequence in chemistry, and a term course in physics numbered PHYS 170 or higher.

For the B.S. degree, additional prerequisites are a two term lecture sequence in chemistry, with associated laboratories; a term course in organic chemistry with its associated laboratory; and two term courses in physics numbered PHYS 170 or higher.

## PLACEMENT PROCEDURES

Placement in MCDB courses is determined by examinations administered at Yale. A student may place out of one or more courses in the BIOL 101–104 sequence. One or more of these foundational biology courses (or equivalent performance on the corresponding biological sciences placement examination) may be explicitly required as prerequisites for upper-level MCDB courses.

Placement in chemistry courses is arranged by the Department of Chemistry. Because required chemistry courses are prerequisite to several MCDB courses, students are strongly encouraged to take general and organic chemistry in the first and/or sophomore years. Students who place out of general chemistry may want to consider taking organic chemistry during the first year. Finishing the prerequisites early allows for a more flexible program in later years.

Acceleration credit awarded in chemistry, mathematics, or physics, or completion of advanced courses in those subjects, is accepted in place of the corresponding prerequisites for the MCDB major. Students who have mathematics preparation equivalent to MATH 115 or higher are encouraged to take additional mathematics courses, such as MATH 120, 222, or 225, or ENAS 151 or 194. Students in the B.A. degree program who have satisfied one or more prerequisites with advanced placement must still complete three term courses in chemistry and physics at Yale, including at least one from each department.

## REQUIREMENTS OF THE MAJOR

**B.A. degree program** The B.A. degree requires a minimum of five and one-half course credits beyond the prerequisites, including five lecture or seminar courses and one laboratory, as follows:

1. Two core courses selected from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300)
2. Two general electives selected from MCDB courses numbered 250 or above, or two additional core courses from the list above. Two laboratory courses, either MCDB 342L and 343L or MCDB 344L and 345L, can be paired for a single elective credit. If used as an elective, these laboratories cannot also fulfill the laboratory requirement
3. One special elective selected from MCDB courses numbered 350 or higher
4. One laboratory from the biological sciences. Laboratories may be selected from MCDB, or Ecology and Evolutionary Biology, or Molecular Biology and Biophysics, or, with permission of the DUS, from Anthropology or Biomedical Engineering
5. The senior requirement, described below

**B.S. degree program** The B.S. degree requires a minimum of nine course credits beyond the prerequisites, including eight lecture or seminar courses and two laboratories, as follows:

1. Three core courses selected from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300)
2. Two general electives selected from MCDB courses numbered 250 or above. Additional core courses from the list above, a second term of organic chemistry, and courses in statistics may be used as general electives. Two laboratory courses, either MCDB 342L and 343L or MCDB 344L and 345L, can be paired for a single elective credit. If used as an elective, these laboratories cannot also fulfill the laboratory requirement
3. One special elective from MCDB courses numbered 350 or higher
4. Two laboratories from MCDB
5. The senior requirement, described below

**The B.S. degree program, intensive major** Requirements for the B.S. degree program, intensive major are the same as those for the B.S. degree except for the senior requirement (see below).

**Independent research courses before senior year** The only independent research course available to students prior to the senior year is MCDB 474. This course is graded pass/fail and contributes to the thirty-six course credits required for the bachelor's degree, but it does not substitute for any MCDB major requirement, including the senior requirement. No independent research course satisfies a laboratory requirement for the MCDB major.

**Independent research courses during senior year** The research courses MCDB 475, 485, 486, and 495, 496 exist primarily to fulfill the senior requirement, and do not satisfy any other requirement for the major. Note that Yale College limits the number of independent study or independent research courses that students may take; see Course Credits and Course Loads in the Academic Regulations. Any independent study course, regardless of its number, is included in the total. No independent research course satisfies a laboratory requirement for the MCDB major.

**Credit/D/Fail** No course taken Credit/D/Fail may be counted toward the MCDB major, including prerequisites.

**Roadmap** See visual roadmap of the requirements.

#### SENIOR REQUIREMENT

In addition to the course requirements described above, all students must satisfy a senior requirement undertaken during the senior year. A booklet listing the senior requirements of each track and degree is available in the office of the DUS (1220B KBT). All students must fill out a checklist of requirements and go over it with the undergraduate registrar, Crystal Adamchek (crystal.adamchek@yale.edu), by the spring term of the junior year.

**B.A. degree program** For the B.A. degree, the senior requirement can be met either by submitting a senior essay of fifteen to twenty pages evaluating current research in a field of biology, or by successful completion of one term of individual research (MCDB 475). A senior choosing to fulfill the requirement with a senior essay must consult with a faculty adviser on the scope and literature of the topic and submit the adviser's written approval to the DUS no later than the course selection period of the term in which the paper is due. The senior essay may be related to the subject matter of a course, but the essay is a separate departmental requirement in addition to any work done in a course and does not count toward the grade in any course. The senior essay must be completed and submitted to the office of the DUS by the last day of classes. Students electing this option should obtain an approval form from the office of the DUS.

**B.S. degree program** For the B.S. degree, the senior requirement is usually fulfilled by completing a yearlong research course, MCDB 485, 486. Alternatively, a student can take two consecutive terms of MCDB 475. With permission of the DUS, students taking two terms of MCDB 475 can begin the project during the spring term of the junior year, continue it over the summer, and complete it during the fall term of the senior year. In all other cases, the senior requirement must be completed during the senior year. Yale College does not grant academic credit for summer research unless the student is enrolled in an independent research course in Yale Summer Session. Seniors working toward the B.S. degree are expected to spend at least ten hours per week in the lab conducting individual research.

**B.S. degree program, intensive major** Requirements for the B.S. degree with an intensive major are the same as those for the B.S. degree except that students fulfill the senior requirement by taking MCDB 495, 496 for four course credits. Seniors in the intensive major are expected to spend at least twenty hours per week in the lab conducting individual research.

#### REQUIREMENTS OF THE NEUROBIOLOGY, BIOTECHNOLOGY, AND QUANTITATIVE BIOLOGY TRACKS

**Neurobiology track** In addition to the core courses for the standard major, the Neurobiology track requires the additional course MCDB 320. One elective is selected from MCDB courses numbered 350 or above and one is selected from BENG 410, CPSC 475, 310, 315, 415, 430, MCDB 361, PSYC 270, or S&DS 101. Other courses may be substituted with the approval of the student's track adviser. (Students should note that PSYC 110 is a prerequisite for many psychology courses but does not substitute as an elective in the Neurobiology track.) The laboratory requirement and the senior requirement are the same as those for the standard major. Students interested in the Neurobiology track should consult an adviser for the track.

##### *Neurobiology track advisers*

P. Forscher, 222 KBT (432-6344)

H. Keshishian, 640A KBT (432-3478)

R. Wyman, 610A KBT (432-3475)

W. Zhong, 616 KBT (432-9233)

**Biotechnology track** In addition to the core courses for the standard major, the Biotechnology track requires the additional course MCDB 370. One elective is selected from MCDB courses numbered 350 or above and one is selected from MB&B 420, 443, BENG 351, 352, 410, 435, CENG 210, 411, CPSC 437, 445, 470, or 475. The laboratory requirement and the senior requirement are the same as those for the standard major. Students interested in the Biotechnology track should consult an adviser for the track.

*Biotechnology track advisers*

R. Breaker, 506 KBT (432-9389)

C. Crews, 452 KBT (432-9364)

F. Isaacs, 802 KBT (432-3783)

K. Nelson, 710A KBT (432-5013)

J. Wolenski, 330 KBT (432-6912)

**Quantitative Biology track** In addition to the core courses for the standard major, the Quantitative Biology track requires the additional course MCDB 330. One elective is selected from MCDB courses numbered 350 or above and one is selected from MCDB 320, 361, 461, MB&B 302, 435, 452, 523, PHYS 402, MATH 246, or CPSC 475. Two laboratories numbered MCDB 201L or above are also required. Students interested in the Quantitative Biology track should consult an adviser for the track.

*Quantitative Biology track advisers*

M. Acar, West Campus B-31 (737-3255)

D. Clark, 224 KBT (432-0750)

T. Emonet, 1048 KBT (432-3516)

D. Kankel, 1118 KBT (432-3532)

**ADDITIONAL INFORMATION AND ADVISING**

The prerequisites for the B.S. degree fulfill most of the usual premedical science requirements. Students who choose the B.A. degree can also prepare for medical school by taking additional premedical courses.

**Selection of courses** A relevant intermediate or advanced course from another department in science, engineering, mathematics, or statistics may be accepted as an elective with permission of the DUS. Many courses in other departments have prerequisites; such prerequisites can be substituted for an upper-level elective with permission of the DUS.

Residential college seminars cannot be substituted for electives and do not count toward the requirements of the major. The MCDB major should not be taken as one of two majors with Molecular Biophysics and Biochemistry, Ecology and Evolutionary Biology, or with Neuroscience.

**Advising** First-year students considering a major in Molecular, Cellular, and Developmental Biology are invited to consult with the DUS and/or a faculty member in MCDB who is a fellow of their residential college. For assistance in identifying a suitable adviser, students should contact the departmental undergraduate registrar, Crystal Adamchek (crystal.adamchek@yale.edu). Students in the Biotechnology, Neurobiology, or Quantitative Biology tracks should consult an adviser for their track (listed above). The course schedules of all MCDB majors (including sophomores intending to major in MCDB) must be signed by a faculty member in the department. The signature of the DUS is required **only** for students who are fulfilling the requirements of two majors or who have been admitted to the simultaneous B.S./M.S. degree program. Students whose regular adviser is on leave can consult the office of the DUS to arrange for an alternate.

Any faculty member with a primary appointment in the MCDB department can serve as a faculty adviser to majors. College faculty advisers available to first-year students are listed below.

BF	D. Kankel	MC	H. Keshishian, T. Pollard
BK	V. Irish, J. Wolenski	MY	S. Bahmanyar, D. Clark, C. Crews, J. Gendron
BR	I. Dawson, T. Emonet, S. Hatzios, J. van Wolfswinkel	PC	J. Carlson, C. Crews
DC	S. Dellaporta, P. Forscher, W. Zhong	SM	J. Rosenbaum
ES	M. Acar	SY	C. Jacobs-Wagner
GH	M. Mooseker, R. Wyman	TC	Y. Jacob, M. Moreno
JE	R. Breaker, T. Emonet, F. Isaacs	TD	S. Holley

**Simultaneous B.S./M.S. degree program** Exceptionally able and well-prepared students may accelerate their professional education by completing a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. Students may not enroll in Yale College for more than eight terms in order to qualify for the simultaneous award of both degrees. It is possible to earn both degrees in fewer than eight terms, but not by the use of acceleration credits. The requirements are as follows:

1. Candidates must satisfy the Yale College requirements for the B.S. degree. Students in the program must complete the core courses for the major and choose their 4 electives from graduate-level courses. One of the electives must be a graduate seminar selected with the approval of the DUS. Grades below B– in graduate courses are not accepted.

- In addition to the courses specified above, students must complete two graduate research courses for six course credits: (a) MCDB 585, a two-credit course taken in the second term of the junior year. At the start of the course, each student forms a committee comprised of the faculty adviser and two faculty members that meets to discuss the research project. Two of the members of this committee must be members of the MCDB faculty. At the end of the course, the student completes a detailed prospectus describing the thesis project and the work completed to date. The committee evaluates an oral and written presentation of the prospectus and determines whether the student may continue in the combined program; (b) MCDB 595, 596, a four-credit, yearlong course that is similar to MCDB 495, 496 and is taken during the senior year. During the course, the student gives an oral presentation describing the work. At the end of the course, the student is expected to present his or her work to the department in the form of a poster presentation. In addition, the student is expected to give an oral thesis defense, followed by a comprehensive examination of the thesis conducted by the thesis committee. Upon successful completion of this examination, as well as all other requirements, the student is awarded the combined B.S./M.S. degree.

Students must also satisfy the requirements of Yale College for the simultaneous award of the bachelor's and master's degrees, including the following:

- To be considered for admission to the program, by the end of their fifth term of enrollment students must have achieved at least two-thirds A or A- grades in all of their courses as well as in all of the courses directly relating to the major, including prerequisites.
- Students must apply in writing to the DUS and obtain departmental approval no later than the last day of classes in their fifth term of enrollment in Yale College.
- Students must have the approval of both the DUS and the DGS to receive graduate credit for the graduate courses they select.
- Graduate work must not be entirely concentrated in the final two terms, and students in the program must take at least six term courses outside the department during their last four terms at Yale and at least two undergraduate courses during their last two terms.
- Students must earn grades of A in at least two of their graduate-level term courses (or in one yearlong course) and have at least a B average in the remaining ones.

For more information, see "Simultaneous Award of the Bachelor's and Master's Degrees" under section K, Special Arrangements, in the Academic Regulations.

#### STUDY ABROAD

Some programs for study abroad are available to MCDB majors; approved programs can fulfill some of the requirements for the major. Interested students should consult the DUS and the Center for International and Professional Experience.

#### REQUIREMENTS OF THE MAJOR

**Prerequisites** *B.A.* – BIOL 101, 102, 103, 104; a two-term lecture sequence in chem; one term of PHYS 170 or above; MATH 115 or above or STAT course at Yale; *B.S.* – BIOL 101, 102, 103, 104; a two-term lecture sequence in chem, with labs, and 1 term of organic chem with lab; two terms of PHYS 170 or above; MATH 115 or above or STAT course at Yale; all courses taken for letter grades

**Number of courses** *B.A.* – 5 courses and 1 lab, totaling at least 5½ course credits; *B.S.* – 8 courses and 2 labs, totaling at least 9 course credits; *B.S., intensive major* – 8 courses and 2 labs, totaling at least 11 course credits; all courses taken for letter grades

**Specific courses required** *Biotechnology track* – MCDB 370; *Neurobiology track* – MCDB 320; *Quantitative Biology track* – MCDB 330

**Distribution of courses** *Standard track* – *B.A.* – 2 core courses from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300); 2 electives numbered MCDB 250 or above (or 2 addtl core courses); 1 elective numbered MCDB 350 or above; 1 biology lab; *B.S.* – 3 core courses from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300); 2 electives numbered MCDB 250 or above (or 2 addtl core courses); 1 elective numbered MCDB 350 or above; 2 MCDB labs; *Biotechnology, Neurobiology, and Quantitative Biology tracks* – same as standard track, with 1 addtl elective

**Senior requirement** *B.A.* – MCDB 475 taken in senior year, or senior essay; *B.S.* – 2 consecutive terms of independent research, MCDB 485, 486 (preferred) or 2 consecutive terms of MCDB 475; *B.S., intensive major* – MCDB 495, 496 in senior year

#### FACULTY OF THE DEPARTMENT OF MOLECULAR, CELLULAR, AND DEVELOPMENTAL BIOLOGY

**Professors** Ronald Breaker, John Carlson, †Lynn Cooley, Craig Crews, Stephen Dellaporta, Paul Forscher, †Mark Hochstrasser, Scott Holley, Vivian Irish, †Akiko Iwasaki, Christine Jacobs-Wagner, Douglas Kankel, †Paula Kavathas, Haig Keshishian, Mark Mooseker, Thomas Pollard, Anna Pyle, Joel Rosenbaum, †Alanna Schepartz, †Hugh Taylor, Robert Wyman

**Associate Professors** Murat Acar, †Sreeranga Chandra, Damon Clark, Thierry Emonet, Valerie Horsley, Farren Isaacs, †Kathryn Miller-Jensen, †Matthew Rodeheffer, Weimin Zhong

**Assistant Professors** Shirin Bahmanyar, David Breslow, Nadya Dimitrova, Joshua Gendron, Stavroula Hatzios, Yannick Jacob, Josien van Wolfswinkel

**Professor Adjunct** Robert Bazell

**Lecturers** †Alexia Belperron, †Surjit Chandhoke, Iain Dawson, Samantha Lin, Maria Moreno, Kenneth Nelson, Julie Park, †Aruna Pawashe, Joseph Wolenski

†A secondary appointment with primary affiliation in another department or school.

## Introductory Courses

\* **MCDB 040b, The Science and Politics of Cancer** Robert Bazell

Fundamentals of cell biology, Darwinian evolution, immunology, and genetics that underlie cancer; the history of cancer science and treatment; historical and current policy issues. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program. SC

\* **MCDB 050a, Immunology and Microbes** Paula Kavathas

Introduction to the immune system and its interaction with specific microbes. Attention both to microbes that cause illness, such as influenza, HIV, and HPV, and to microbes that live in harmony with humans, collectively called the microbiome. Readings include novels and historical works on diseases such as polio and AIDS. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program. SC RP

\* **MCDB 065a, The Science and Politics of HIV/AIDS** Robert Bazell

Study of the basic virology and immunology of HIV/AIDS, along with its extraordinary historical and social effects. Issues include the threat of new epidemics emerging from a changing global environment; the potential harm of conspiracy theories based on false science; and how stigmas associated with poverty, gender inequality, sexual preference, and race facilitate an ongoing epidemic. For all first-year students regardless of whether they are considering a science major. Prerequisite: AP Biology or equivalent. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program. SC

\* **MCDB 103b, Cancer** Alexia Belperron

Introduction to the biology of cancer, with a focus on leukemia, skin cancer, and cancers linked to infection. Topics include genetics, biochemistry, immunity, infection agents, and challenges for prevention and treatment. Intended for non-science majors and underclassmen. High school biology required. SC

**MCDB 105a or b / MB&B 105a or b, Biology, the World, and Us** Ronit Kaufman and 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

\* **MCDB 106a / E&EB 106a / HLTH 155a, Biology of Malaria, Lyme, and Other Vector-Borne Diseases** Alexia Belperron

Introduction to the biology of pathogen transmission from one organism to another by insects; special focus on malaria, dengue, and Lyme disease. Biology of the pathogens including modes of transmission, establishment of infection, and immune responses; the challenges associated with vector control, prevention, development of vaccines, and treatments. Intended for non-science majors; preference to freshmen and sophomores. Prerequisite: high school biology. SC

\* **MCDB 109b, Immunity and Contagion** Paula Kavathas

Introduction to the basics of the immune system; strategies to fight pathogens while maintaining harmony with our microbiome. Discussion of specific microbes such as influenza, HIV, and HPV; historical analysis of the polio vaccine and the AIDS epidemic. Enrollment limited to freshmen and sophomores. SC

## Intermediate and Advanced Courses

**MCDB 200b, Molecular Biology** Anna Pyle and Farren Isaacs

A study of the fundamental principles of molecular biology, including the experimental methodologies used in biological research. Topics include the structure, function, and chemical behavior of biological macromolecules (DNA, RNA, and protein), chromosome and genome organization, replication and maintenance of the genome, transcriptional and translational regulation, microRNAs and other noncoding RNAs, RNA processing, systems biology, and synthetic biology. Designed to provide an accelerated venue for MCDB majors and other students seeking to understand the molecular basis for gene expression and the resultant implications for medicine and biological engineering. Prerequisites: CHEM 161, 165, or 167 (or CHEM 112, 114, or 118), and BIOL 101 or permission of instructor. SC

**MCDB 201Lb, Molecular Biology Laboratory** Maria Moreno

Basic molecular biology training in a project-based laboratory setting. Experiments analyze gene function through techniques of PCR, plasmid and cDNA cloning, DNA sequence analysis, and protein expression and purification. Instruction in experimental design, data analysis, and interpretation. Concurrently with or after MCDB 200, or with permission from instructor. For freshmen and sophomores interested in research integrated laboratory experience. Special registration procedures apply. Interested students must contact the instructor and attend an organizational meeting during the first week of classes. WR, SC ½ Course cr

\* **MCDB 202a, Genetics** Stephen Dellaporta and Joshua Gendron

An introduction to classical, molecular, and population genetics of both prokaryotes and eukaryotes and their central importance in biological sciences. Emphasis on analytical approaches and techniques of genetics used to investigate mechanisms of heredity and variation. Topics include transmission genetics, cytogenetics, DNA structure and function, recombination, gene mutation, selection, and recombinant DNA technology. Prerequisite: BIOL 103 or equivalent performance on the corresponding biological sciences placement examination. SC RP

\* **MCDB 203La, Laboratory for Genetics** Iain Dawson

Introduction to laboratory techniques used in genetic analysis. Genetic model organisms—bacteria, yeast, *Drosophila*, and *Arabidopsis*—are used to provide practical experience with various classical and molecular genetic techniques including cytogenetics; complementation,

epistasis, and genetic suppressors; mutagenesis and mutant analysis, recombination and gene mapping, isolation and manipulation of DNA, and transformation of model organisms. Concurrently with or after MCDB 202. SC ½ Course cr

**MCDB 205b, Cell Biology** Thomas Pollard, Megan King, Shirin Bahmanyar, and David Breslow

A comprehensive introductory course in cell biology. Emphasis on the general principles that explain the molecular mechanisms of cellular function. Prerequisites: BIOL 101 and 102, or equivalent performance on the corresponding biological sciences placement examinations, or a score of 5 on the Advanced Placement test in Biology, or a score of 710 or above on the SAT Biology M test, or MCDB 200. SC

**MCDB 210a, Developmental Biology** Scott Holley, Douglas Kankel, and Josephina van Wolfswinkel

A survey of the molecular and genetic control of embryonic development, cell-cell communication, and cell differentiation. Emphasis on mechanistic investigation in model organisms that reveal fundamental concepts explaining human birth defects and disease. Topics include gastrulation; neural and mesoderm induction; limb development; heart and vascular development; craniofacial development; adult and embryonic stem cells; regeneration; evolution and development. Prerequisites: BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations. SC

**MCDB 221La, Model Organisms in Biological Research** Maria Moreno

An introduction to research and common methodologies in the biological sciences, with emphasis on the utility of model organisms. Techniques and methods commonly used in biochemistry, cell biology, genetics, and molecular and developmental biology; experimental design; data analysis and display; scientific writing. With permission of instructor or concurrently with or after BIOL 101, 102 or 103. WR, SC ½ Course cr

**MCDB 250b, Biology of Reproduction** Hugh Taylor and Seth Guller

Introduction to reproductive biology, with emphasis on human reproduction. Development and hormonal regulation of reproductive systems; sexuality, fertilization, and pregnancy; modern diagnosis and treatment of reproductive and developmental disorders; social and ethical issues. BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations, or a score of 5 on the Advanced Placement test in Biology, or a score of 710 or above on the SAT Biology M test SC

**MCDB 251Lb, Laboratory for Biology of Reproduction and Development** Hugh Taylor, Seth Guller, and Shannon Whirlledge

Laboratory focus on aspects of human reproductive biology and connections with normal reproductive outcomes. Clinically relevant consideration of human tissue and cell models to study ovarian, uterine, and placental structure and function. Testing of the role of tissue specific cellular differentiation; human trophoblast function; and the roles of steroid hormones in the regulation of uterine, placental, and ovarian function. Mouse tissue models will be employed. Enrollment limited. Concurrently with or after MCDB 210 or 250. Not open to first-year students. Special registration procedures apply; students must consult the instructor prior to the first week of classes. SC ½ Course cr

**MCDB 290b, Microbiology** Christine Jacobs-Wagner and Stavroula Hatzios

Cell structure of bacteria, bacterial genetics, microbial evolution and diversity, bacterial development, microbial interaction, chemotaxis and motility, gene regulation, microbial genomics and proteomics, CRISPR, metabolism, infectious diseases, mechanisms of pathogenesis, host defense systems, viruses, gut microbiota in health and disease. Prerequisites: BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations; or one term of biochemistry, or cell biology, or genetics; or with permission of instructor. SC

\* **MCDB 291Lb, Laboratory for Microbiology** Iain Dawson

Practical approaches used when working with microbes, primarily bacteria. Topics include microscopy, culture techniques, biochemical/metabolic assays, and basic environmental and medical microbiology. Concurrently with or after MCDB 290. Electronic permission key required; students should contact the instructor prior to the first class meeting. SC ½ Course cr

\* **MCDB 300a / MB&B 200a, 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

\* **MCDB 301La or b / MB&B 251La 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. Please note: During the fall term, this course runs as two sections, Tuesday or Thursday from 1.15pm-5.15pm, for the entire semester. During the spring term it meets twice a week, Tuesday and Thursday, but only for the first half of the semester. Prerequisite: BIOL 101. SC ½ Course cr

\* **MCDB 303Lb, Advanced Molecular Biology Laboratory** Maria Moreno and Timothy Nelson

A laboratory course that provides advanced biology research skills. Weekly workshops focus on laboratory practice, experimental design, data analysis, reading of primary literature, scientific presentations, and scientific writing skills. Application of these skills in project-based laboratory training sponsored by a faculty member. Enrollment limited. Special registration procedures apply; interested students must contact the instructor and attend an organizational meeting. This class is recommended to students in the sciences who are in their junior year and will be completing a senior research project requirement for graduation. SC RP

\* **MCDB 310a / BENG 350a, Physiological Systems** Mark Saltzman and Stuart Campbell

Regulation and control in biological systems, emphasizing human physiology and principles of feedback. Biomechanical properties of tissues emphasizing the structural basis of physiological control. Conversion of chemical energy into work in light of metabolic control and temperature regulation. Prerequisites: CHEM 165 or 167 (or CHEM 113 or 115), or PHYS 180 and 181; MCDB 120, or BIOL 101 and 102. SC

**MCDB 315b, Pathobiology** S. David Hudnall, Jon Morrow, Anita Huttner, Jeffrey Sklar, and Gilbert Moeckel

Mechanisms of human disease from a pathologic perspective. Includes sections devoted to systemic pathobiology, hematologic disease, gastrointestinal disease, renal disease, and cancer genetics. Subjects covered include cell and tissue injury, disordered physiology, inflammatory disease, and neoplastic disease. Enrollment limited; preference to junior and senior majors in MCDB or MB&B. Prerequisites: MCDB 205, 300, or 310 SC RP

**MCDB 320a / NSCI 320a, Neurobiology** Haig Keshishian and Paul Forscher

The excitability of the nerve cell membrane as a starting point for the study of molecular, cellular, and systems-level mechanisms underlying the generation and control of behavior. Prerequisites: year of college-level chemistry; a course in physics is strongly recommended. SC

**MCDB 321La / NSCI 321La, Laboratory for Neurobiology** Haig Keshishian, Robert Wyman, and Paul Forscher

Introduction to the neurosciences. Projects include the study of neuronal excitability, sensory transduction, CNS function, synaptic physiology, and neuroanatomy. Concurrently with or after MCDB 320. SC ½ Course cr

**MCDB 330a / MB&B 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

\* **MCDB 342La, Laboratory in Nucleic Acids I** Kenneth Nelson

A project from a research laboratory within the MCDB department, using technologies from molecular and cell biology. Laboratories meet twice a week for the first half of the term. Concurrently with or after MCDB 202, 205, or 300. Enrollment limited. Special registration procedures apply; students should contact the instructor during January of the year you intend to take the course. SC ½ Course cr

\* **MCDB 343La, Laboratory in Nucleic Acids II** Kenneth Nelson

Continuation of MCDB 342L to more advanced projects in molecular and cell biology, such as making and screening cDNA libraries, microarray screening and analysis, or next-generation DNA sequencing. Laboratories meet twice a week for the second half of the term. Enrollment limited. Special registration procedures apply; students should contact the instructor during January of the year you intend to take the course. MCDB 342L or permission of instructor. SC ½ Course cr

\* **MCDB 344Lb, Experimental Techniques in Cellular Biology** Joseph Wolenski

An inquiry-based approach to research in cell and molecular biology, with emphasis on experimental techniques commonly used in modern biomedical laboratories. Research is module-based and covers pertinent and timely topics. Methods include SDS-PAGE, immunoblotting, immunoprecipitation of proteins, column chromatography, mammalian cell culture, cell fractionation, cell transfection, plasmid design, DNA purification, PCR, and phase contrast and confocal microscopy. Meets during January and February. Prerequisite: MCDB 205. Special registration procedures apply; interested students must contact the instructor at least eighteen months in advance. SC ½ Course cr

\* **MCDB 345Lb, Experimental Strategies in Cellular Biology** Joseph Wolenski

Continuation of MCDB 344L, with increased emphasis on experimental design, independent research, and presentation of data. Students develop semi-independent research projects in modern biomedical research. Emphasis on key components of being a successful principal investigator, including benchwork, seminar presentations, lab meetings, and critical analysis of data. Prepares for MCDB 475, 485, or 495. Meets during March and April. Prerequisite: MCDB 344L. Special registration procedures apply; interested students should contact the instructor. SC ½ Course cr

\* **MCDB 350a, Epigenetics** Josephina van Wolfswinkel and Nadya Dimitrova

Study of epigenetic states and the various mechanisms of epigenetic regulation, including histone modification, DNA methylation, nuclear organization, and regulation by non-coding RNAs. Detailed critique of papers from primary literature and discussion of novel technologies, with specific attention to the impact of epigenetics on human health. Introductory courses (BIOL 101-104) and two MCDB 200-level courses (strongly recommended: MCDB 202 and MCDB 200 or MCDB 210) or instructor permission. SC

\* **MCDB 355a, The Cytoskeleton, Associated Proteins, and Disease** Surjit Chandhoke

In-depth discussion of the cytoskeleton, proteins associated with the cytoskeleton, and diseases that implicate members of these protein families. Preference given to seniors in the MCDB major. Prerequisites: BIOL 101-104 *and* at least one MCDB 200-level course. SC

**MCDB 361b / BENG 465b / MB&B 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

\* **MCDB 370b, Biotechnology** Craig Crews, Ronald Breaker, Timothy Nelson, and Joseph Wolenski

The principles and applications of cellular, molecular, and chemical techniques that advance biotechnology. The most recent tools and strategies used by industrial labs, academic research, and government agencies to adapt biological and chemical compounds as medical treatments, as industrial agents, or for the further study of biological systems. Prerequisite: MCDB 200, 202, or 300. SC

\* **MCDB 387b, The Eukaryotic Cell Cycle** Iain Dawson

The regulation and coordination of the eukaryotic cell cycle examined by means of a detailed critique of primary literature. Particular attention to the role of the cell cycle in the processes of development and differentiation and in cancer and other diseases. Students develop an understanding of experimental approaches to problem solving. Enrollment limited, with preference to juniors and seniors. Prerequisites: BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations; MCDB 202, 205, or 210. Electronic permission key required. Students must contact the instructor prior to the first class meeting. SC

\* **MCDB 415b, Cellular and Molecular Physiology** Emile Boulpaep

Study of the processes that transfer molecules across membranes. Classes of molecular machines that mediate membrane transport. Emphasis on interactions among transport proteins in determining the physiologic behaviors of cells and tissues. Intended for seniors majoring in the biological sciences. Recommended preparation: MCDB 205, 310, 320, or permission of instructor. SC

\* **MCDB 425a / MB&B 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

\* **MCDB 430a, Biology of the Immune System** Eric Meffre, David Schatz, Peter Cresswell, Jordan Pober, Joao Pedro Pereira, Ruslan Medzhitov, Craig Roy, Nikhil Joshi, Aaron Ring, Noah Palm, Kevan Herold, Carla Rothlin, and Carrie Lucas

The development of the immune system. Cellular and molecular mechanisms of immune recognition. Effector responses against pathogens. Immunologic memory and vaccines. Human diseases including allergy, autoimmunity, immunodeficiency, and HIV/AIDS. After MCDB 300. SC

\* **MCDB 435a, Landmark Papers in Cell Biology** Joel Rosenbaum and Mark Mooseker

Discussion and critical evaluation of selected research papers that were important in determining the directions of modern cell biological research. Emphasis on the nature of the problem, evaluation of the experimental approaches and results, and the authors' interpretation of the results. Grade dependent on weekly discussion by all participants. Seniors only. Students should contact the instructor prior to the first week of classes. Prerequisites: courses in cell biology, biochemistry, and genetics, or permission of instructor. SC

\* **MCDB 450b, The Human Genome** Stephen Dellaporta

A focus on the primary scientific literature covering the principles of genomics and its application to the investigation of complex human traits and diseases. Topics include the technology of genome sequencing and resequencing, the characterization of sequence and structural variation in human populations, haplotype and linkage disequilibrium analysis, genome-wide association studies, the comparative genomics of humans and our closest relatives, and personalized genomics and medicine. Enrollment limited to 15. Students should contact the instructor prior to the first week of classes. Prerequisite: MCDB 202; a course in statistics is strongly recommended. SC

**MCDB 452b / MB&B 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

\* **MCDB 461b, Concepts and Applications in Systems Biology** Murat Acar

Analysis of the primary scientific literature on the topics of gene network design, stochasticity in gene expression, and evolution of genes and networks, in the context of both prokaryotic and eukaryotic systems. Critique of the approaches, data analysis, controls, results, and conclusions of selected current and classic papers in systems biology. Prerequisite: MCDB 261 or 361, or another MCDB course with permission of instructor. SC

\* **MCDB 474a or b, Independent Research** Joseph Wolenski and Staff

Research project under faculty supervision taken Pass/Fail. This is the only independent research course available to underclassmen. Students are expected to spend approximately ten hours per week in the laboratory. To register, the student must submit a form, which is available at <http://mcdy.yale.edu/forms> as well as on the course site on Canvas@Yale, and a written plan of study with bibliography,



approved by the faculty research adviser. The form and proposal must be uploaded to Canvas@Yale by the end of the second week of classes. A final research report is required at the end of the term. Students who take this course more than once must reapply each term. Guidelines for the course should be obtained from the office of the director of undergraduate studies or downloaded from the Canvas@Yale server.

**\* MCDB 475a or b, Senior Independent Research** Joseph Wolenski and Staff

Research project under faculty supervision, ordinarily taken to fulfill the senior requirement. This course is only available to MCDB seniors and they are awarded a letter grade. Students are expected to spend approximately ten hours per week in the laboratory. To register, the student must prepare a form, which is available at <http://mcd.b.yale.edu/forms> as well as on the course site on Canvas@Yale, and a written plan of study with bibliography, approved by the faculty research adviser. The form and proposal must be uploaded to Canvas@Yale by the end of the second week of classes. The final research paper is due in the hands of the sponsoring faculty member, with a copy uploaded to Canvas@Yale, by the last day of classes. Students who take this course more than once must reapply each term; students planning to conduct two terms of research should consider enrolling in MCDB 485, 486. Students should line up a research laboratory during the term preceding the research. Fulfills the senior requirement for the B.A. degree if taken in the senior year. Two consecutive terms of this course fulfill the senior requirement for the B.S. degree if at least one term is taken in the senior year.

**\* MCDB 482a, Advanced Seminar in Cell Biology: Intracellular Signal Transduction** Craig Crews

Discussion of intracellular signal transduction pathways. Detailed critique of experimental approaches, controls, results, and conclusions of selected current and classic papers in this field. sc

**\* MCDB 485a and MCDB 486b, Senior Research** Joseph Wolenski, Yannick Jacob, and David Breslow

Individual two-term laboratory research projects under the supervision of a faculty member. For MCDB seniors only. Students are expected to spend ten to twelve hours per week in the laboratory, and to make presentations to students and advisers. Written assignments include a short research proposal summary due at the beginning of the first term, a grant proposal due at the end of the first term, and a research report summarizing experimental results due at the end of the second term. Students are also required to present their research in either the fall or the spring term. A poster session is held at the end of the spring term. Students should line up a research laboratory during the term preceding the research. Guidelines for the course may be obtained at <http://mcd.b.yale.edu/forms> and on the course site on Canvas@Yale. Written proposals are due by the end of the second week of classes. Fulfills the senior requirement for the B.S. degree if taken in the senior year.

**\* MCDB 486b, Senior Research** Joseph Wolenski, Stavroula Hatzios, and David Breslow

Individual two-term laboratory research projects under the supervision of a faculty member. For MCDB seniors only. Students are expected to spend ten to twelve hours per week in the laboratory, and to make presentations to students and advisers. Written assignments include a short research proposal summary due at the beginning of the first term, a grant proposal due at the end of the first term, and a research report summarizing experimental results due at the end of the second term. Students are also required to present their research in either the fall or the spring term. A poster session is held at the end of the spring term. Students should line up a research laboratory during the term preceding the research. Guidelines for the course may be obtained at <http://mcd.b.yale.edu/forms> and on the course site on Classes\*v2. Written proposals are due by the end of the second week of classes. Fulfills the senior requirement for the B.S. degree if taken in the senior year.

**\* MCDB 495a and MCDB 496b, Senior Research Intensive** Joseph Wolenski, Yannick Jacob, and David Breslow

Individual two-term directed research projects in the field of biology under the supervision of a faculty member. For MCDB seniors only. Before registering, the student must be accepted by a Yale faculty member with a research program in experimental biology and obtain the approval of the instructor in charge of the course. Students spend approximately twenty hours per week in the laboratory, and make written and oral presentations of their research to students and advisers. Written assignments include a short research proposal summary due at the beginning of the first term, a grant proposal due at the end of the first term, and a research report summarizing experimental results due at the end of the second term. Students must attend a minimum of three research seminar sessions (including their own) per term. Students are also required to present their research during both the fall and spring terms. A poster session is held at the end of the spring term. Guidelines for the course may be obtained at <http://mcd.b.yale.edu/forms> and on the course site on Canvas@Yale. Written proposals are due by the end of the second week of classes. Fulfills the senior requirement for the B.S. degree with an intensive major.

2 Course cr per term

**\* MCDB 496b, Senior Research Intensive** Joseph Wolenski, Stavroula Hatzios, and David Breslow

Individual two-term directed research projects in the field of biology under the supervision of a faculty member. For MCDB seniors only. Before registering, the student must be accepted by a Yale faculty member with a research program in experimental biology and obtain the approval of the instructor in charge of the course. Students spend approximately twenty hours per week in the laboratory, and make written and oral presentations of their research to students and advisers. Written assignments include a short research proposal summary due at the beginning of the first term, a grant proposal due at the end of the first term, and a research report summarizing experimental results due at the end of the second term. Students must attend a minimum of three research seminar sessions (including their own) per term. Students are also required to present their research during both the fall and spring terms. A poster session is held at the end of the spring term. Guidelines for the course may be obtained at <http://mcd.b.yale.edu/forms> and on the course site on Classes\*v2. Written proposals are due by the end of the second week of classes. Fulfills the senior requirement for the B.S. degree with an intensive major.

2 Course cr