MOLECULAR, CELLULAR, AND DEVELOPMENTAL BIOLOGY

Director of undergraduate studies: Douglas Kankel, 1220B KBT, 432-3839, crystal.adamchek@yale.edu, www.mcdb.yale.edu

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


Associate Professors  Thierry Emonet, Martín García-Castro, Scott Holley, †Akiko Iwasaki, Weimin Zhong

Assistant Professors  Murat Acar, †Sreeganga Chandra, Damon Clark, Nicole Clay, Valerie Horsley, Farren Isaacs, †Kathryn Miller-Jensen, †Matthew Rodeheffer

Lecturers  Carol Bascom-Slack, †Alexia Belperron, Brett Berke, Emile Boulpaep, Iain Dawson, Mary Klein, Maria Moreno, Kenneth Nelson, †Aruna Pawashe, Barry Pickos, †William Segraves, Joseph Wolenski

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

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 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 computational biology. Interdisciplinary opportunities are available within the major in the biotechnology and neurobiology 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. 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 director of undergraduate studies and the Center for International and Professional Experience (http://cipe.yalecollege.yale.edu).

Prerequisites  The basic science courses required of all MCDB majors are BIOL 101, 102, 103, 104; CHEM 112, 113, or 114, 115, or 118, taken with their associated laboratories, as well as one term of organic chemistry with laboratory (CHEM 124, 125 with 222L, 223L satisfies both chemistry requirements); two terms of PHYS 170, 171 or higher; and one term of MATH 115 or above (excluding MATH 190). The second term of organic chemistry, CHEM 230, may be used as an elective in the major. Note that these prerequisites fulfill most of the usual premedical science requirements.

Acceleration credit awarded in chemistry, mathematics, and physics, or completion of advanced courses in those departments, is accepted instead 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, 121, 222, or 225.

Placement  For students in the Class of 2016 and subsequent classes, placement in MCDB courses is determined by examinations administered at Yale. Based on the results of the examinations, a student may place out of one or more courses in the BIOL 101–104 sequence. However, one or more of these introductory Biology courses may be explicitly required as prerequisites for upper-level MCDB courses.

Students in the Class of 2015 and previous classes who have scored 710 or higher on the SAT subject matter Biology M test, or who have scored 5 on the Advanced Placement test in Biology, may be exempt from taking BIOL 101, 102, 103, and 104. Students with equivalent scores on one of the corresponding chemistry tests, or who have scored 7 on an International Baccalaureate higher-level examination in an appropriate subject, may also be exempt from taking BIOL 101, 102, 103, and 104.

Placement in chemistry courses is arranged by the Chemistry department. Because the required chemistry courses are prerequisite to several MCDB courses, students are strongly urged to take general and organic chemistry in the freshman and sophomore years. Students who place out of general chemistry should take organic chemistry during their freshman year. Finishing the prerequisites early allows for a more flexible program in later years.

Requirements of the major  Beyond the prerequisites, the B.A. degree requires at least eight course credits, including seven lecture courses or seminars and two laboratories, as follows:
1. Three core courses: either MCDB 200 or 202; either MCDB 205 or 210; either MCDB 300 or MB&B 300
2. Three electives, for three course credits, from MCDB courses numbered 200 or above
3. One elective, for one course credit, from MCDB courses numbered 350 or above
4. Two MCDB laboratories numbered 201L or above
5. The senior requirement, described below

Residential college seminars 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 or with Ecology and Evolutionary Biology.

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

Neurobiology track  In addition to the three core courses for the standard major, the neurobiology track requires the core course MCDB 320, as well as one MCDB elective numbered 350 or above and two electives chosen from BENG 410, CPSC 475, MCDB 240, 310, 315, 415, 430, 440, PSYC 270, and either STAT 101 or PSYC 200. 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.) Two laboratories chosen from MCDB courses numbered 201L or above are also required. Students interested in the neurobiology track should consult an adviser for the track. Advisers whose names are listed followed by "[F]" may be consulted during the fall term; others may be consulted during either term.

Neurobiology track advisers
P. Forscher, 222 KBT (432-6344)
H. Keshishian, 640A KBT (432-3478)
R. Wyman [F], 610A KBT (432-3475)
W. Zhong, 616 KBT (432-9233)

Biotechnology track  In addition to the three core courses for the standard major, the biotechnology track requires the core course MCDB 370 and three electives chosen from any MCDB course numbered 200 or above, MB&B 420, 421, 443, BENG 351, 352, 410, 435, 457, 464, CENG 210, 411, 412, CPSC 437, 445, 470, or 475. Two laboratories are required: either two from MCDB (including at least one from MCDB 341L to MCDB 345L), or BENG 355L, 356L or CENG 412. Students interested in the biotechnology track should consult an adviser for the track. Advisers whose names are listed followed by "[F]" may be consulted during the fall term; others may be consulted during either term.

Biotechnology track advisers
R. Breaker, 506 KBT (432-9389)
X. W. Deng [F], 352B OML (432-8908)
K. Nelson, 710A KBT (432-5013)
J. Wolenski, 330 KBT (432-6912)

Electives in all tracks If both MCDB 200 and 202 are taken, one counts as a core course and the other as an elective. If both MCDB 205 and 210 are taken, one counts as a core course and the other as an elective. Two laboratory courses, either MCDB 342L and 343L or 344L and 345L, can be used together as one elective credit. If used as an elective, these laboratories cannot also fulfill the laboratory requirement. 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 director of undergraduate studies. Residential college seminars cannot be substituted for electives.

Many of the courses in other departments listed above have prerequisites; such prerequisites can be substituted for an upper-level elective with permission of the director of undergraduate studies.

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 requirements of each track and degree is available in the office of the director of undergraduate studies (1220B KBT). All students must fill out a checklist of requirements and go over it with the undergraduate registrar, Crystal Adamchek, by the spring term of the junior year. For the B.A. degree the senior requirement can be met in any one of three ways: by submitting a senior essay of fifteen to twenty pages evaluating current research in a field of biology; by successful completion of one term of tutorial work (MCDB 470); 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 director of undergraduate studies 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 director of undergraduate studies by the last day of classes. Students electing this option should obtain an approval form from the office of the director of undergraduate studies.

B.S. degree  The requirements for the B.S. degree are the same as for the B.A. degree except for the senior requirement, which differs in its greater emphasis on individual research. The senior requirement for the B.S. is usually fulfilled by completing a yearlong research
course, MCDB 485, 486. Alternatively, two consecutive terms of MCDB 475 can be taken during the senior year. In the case of a two-term project in MCDB 475, it is possible for a student to 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 ten hours per week conducting individual research.

**B.S. degree, intensive major** Requirements for the B.S. degree with an intensive major are the same as those for the B.A. degree except that students take an additional seminar numbered MCDB 350 or higher and fulfill the senior requirement by taking MCDB 495, 496, Intensive Research, for four course credits. The additional seminar does not need to be taken during the senior year. Seniors in the intensive major are expected to spend twenty hours per week conducting individual research.

**Research courses before senior year** The research courses MCDB 475, 485, 486, and 495, 496 exist primarily to fulfill the senior requirement. Some students may wish to take MCDB 475 earlier in their course of study. This contributes to the thirty-six course credits required for graduation, but does not substitute for any of the other requirements for the major, including the senior requirement. Students may take up to three credits in MCDB 475 (MCDB 485, 486 counts as two terms of MCDB 475 in this calculation) during their undergraduate career.

**Laboratory preparation for research** Students with an interest in particular problems in cellular and molecular biology and who are planning to undertake independent research may wish to take one or more of the following laboratories first: MCDB 303L, 342L, 343L, 344L, or 345L.

**Combined 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 three or four core courses for the major (depending on track) and choose their three or four electives from graduate-level courses. One of these electives must be a graduate seminar selected with the approval of the director of undergraduate studies. Grades below B– in graduate courses are not accepted.

2. 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 typically 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, 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:

1. 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 course credits as well as in all of the course credits directly relating to the major, including prerequisites.

2. Students must apply in writing to the director of undergraduate studies 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 director of undergraduate studies and the director of graduate studies to receive graduate credit for the graduate courses they select.

3. 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.

4. Students must earn grades of A in at least two of their graduate-level term courses (or in one year 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 "Special Arrangements" in the Academic Regulations.

**Advising** Freshmen considering a major in Molecular, Cellular, and Developmental Biology are invited to consult with the director of undergraduate studies 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. Students in the neurobiology
or biotechnology track 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 director of undergraduate studies 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 director of undergraduate studies to arrange for an alternate.

Any member of the MCDB department can serve as a faculty adviser to majors. College faculty advisers available to freshmen are listed below.

<table>
<thead>
<tr>
<th>Track</th>
<th>Adviser</th>
</tr>
</thead>
<tbody>
<tr>
<td>BK</td>
<td>M. García-Castro, J. Wolenski</td>
</tr>
<tr>
<td>BR</td>
<td>N. Clay, I. Dawson</td>
</tr>
<tr>
<td>CC</td>
<td>M. Mooseker [F], R. Wyman [F]</td>
</tr>
<tr>
<td>DC</td>
<td>C. Bascom-Slack, V. Irish, W. Zhong</td>
</tr>
<tr>
<td>TD</td>
<td>S. Holley</td>
</tr>
<tr>
<td>JE</td>
<td>R. Breake, T. Emonet, F. Isaacs, T. Nelson</td>
</tr>
<tr>
<td>MC</td>
<td>X. W. Deng, H. Keshishian, K. Nelson, F. Slack</td>
</tr>
<tr>
<td>PC</td>
<td>J. Carlson, C. Crews</td>
</tr>
<tr>
<td>SM</td>
<td>S. DellaPorta [F], D. Kankel, J. Rosenbaum [Sp]</td>
</tr>
<tr>
<td>ES</td>
<td>to be announced</td>
</tr>
<tr>
<td>JE</td>
<td>R. Breake, T. Emonet, F. Isaacs, T. Nelson</td>
</tr>
<tr>
<td>TC</td>
<td>S. Altman [F]</td>
</tr>
</tbody>
</table>

**Requirements of the Major**

**Prerequisites**

- **Biol:** 101, 102, 103, 104; CHEM 112, 113, or 114, 115, or 118, with labs, and 1 term of organic chem with lab (CHEM 124, 125 with 222L, 223L satisfies both reqs); PHYS 170, 171 or higher; MATH 115 or above (except MATH 190); all courses taken for letter grades

**Number of courses**

- **B.A.**—at least 7 courses and 2 labs beyond prereqs taken for letter grades, totaling at least 8 course credits (incl senior req); **B.S.**—9 courses and 2 labs beyond prereqs taken for letter grades, totaling at least 10 course credits (incl senior req); **B.S., intensive major**—10 courses and 2 labs beyond prereqs taken for letter grades, totaling at least 13 course credits (incl senior req)

**Specific courses required**

- All tracks—MCDB 200 or 202; MCDB 205 or 210; MCDB 300 or MB&B 300; Neurobiology track—MCDB 320; Biotechnology track—MCDB 370
- Distribution of courses
  - Standard track—3 electives from MCDB numbered 200 or above; 1 addtl MCDB course numbered 350 or above; 2 labs in MCDB numbered 201L or above; Neurobiology and biotechnology tracks—3 electives and two labs as specified

**Senior requirement**

- **B.A.**—MCDB 470 or 475 taken in senior year, or senior essay; **B.S.**—2 consecutive terms of MCDB 475, at least 1 in senior year, or MCDB 485, 486

**Intensive major**

- 1 addtl sem numbered MCDB 350 or higher; MCDB 495, 496 in senior year

**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. Prerequisite: a score of 5 on the Advanced Placement test in Biology or equivalent. Enrollment limited to freshmen; preregistration required. May not be taken after CSSY 290. SC

*MCDB 050a, Immunology and Microbes*  
Paula Kavathas
  
Responses generated by the human immune system to various classes of pathogens. Attention both to pathogenic microbes and to microbes in the human microbiome that do not normally produce disease. Discussion of specific microbes, including influenza, HIV, and HPV; historical analysis of the development of vaccines and of the AIDS epidemic. Enrollment limited to freshmen. Preregistration required; see under Freshman Seminar Program. SC RP

*MCDB 105b, 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. SC

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

*MCDB 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 and Lyme disease. Biology of the pathogens including modes of transmission and establishment of infection; immune responses and the associated challenges to prevention and treatment. 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 RP
MCDB 123b, Genes and Environment  Jo Handelsman and Nichole Broderick
The nature of biological thought and inquiry explored through study of the interplay between genes and the environment. Influence of the microbial world on the physiology and evolution of organisms. Tools from molecular biology and genomics are used to examine the effects of internal and external factors on gene expression, how the process of gene expression leads to observable characteristics, and the relationship between bacterial gene expression and human survival. Intended for non-science majors.  SC

[ MCDB 150, The Human Population Explosion ]

*MCDB 166b, From Microbes to Molecules I  Jo Handelsman and staff
The first term of a yearlong introduction to biology and chemistry through research on soil bacteria. Focus on the discovery of antibiotics from soil bacteria isolated from the Yale campus. Diversity of life, structure of biomolecules, components of a cell, molecular basis of gene expression, heritability, and symbiosis. Comparison with eukaryotic molecular and cellular biology. Class sessions include lecture and laboratory components. Enrollment limited to freshmen and sophomores.  SC  1½ Course cr

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, and systems biology. Designed to provide an accelerated venue for MCDB majors and other students seeking to understand the molecular basis for gene expression and biological function. Prerequisites: CHEM 112, 114, or 118, and BIOL 101 or equivalent performance on the corresponding biological sciences placement examination; or permission of instructor.  SC

Psychology: AdvSci NeuroTrk

*MCDB 2011b, 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. For freshmen and sophomores. Concurrently with or after MCDB 200. 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 staff
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

Psychology: AdvSci NeuroTrk

RP

*MCDB 203La, Laboratory for Genetics  Iain Dawson and William Leiserson
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 and staff
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 and staff
Cellular differentiation and its genetic and molecular control; fertilization, cleavage, and morphogenesis of plants and animals; polarity and positional information; organogenesis and development of specialized tissues; evolution and development. Prerequisites: BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations.  SC

MCDB 211La, Model Systems 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. Concurrently with or after BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations, or with permission of instructor.  SC  ½ Course cr

*MCDB 230b / MKSB 230b, Rain Forest Expedition and Laboratory  Scott Strobel and staff
Preparation for a two-week expedition to one of the world’s rain forests during spring break and for a ten-week summer laboratory experience using samples collected during the expedition. Integrated topics draw on the fields of ecology, microbiology, chemistry, pharmacology, molecular biology, and bioinformatics. Students participate in an original scientific project from field biology to natural
product characterization. After one year of introductory biology or equivalent; after or concurrently with one term of organic chemistry. Limited enrollment. Funding for major travel expenses and summer research provided.  SC

MCDB 240b, Biology of Reproduction  Hugh Taylor and Mary Klein
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. Prerequisites: 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 241Lb, Laboratory for Biology of Reproduction and Development  Mary Klein
Laboratory investigation of reproductive and developmental processes in classic vertebrate and invertebrate systems, with emphasis on mammalian reproduction and development. Topics include gametogenesis, ovulation, hormonal control of reproduction, and investigation of embryogenesis in the mouse, frog, and fruit fly. Enrollment limited. Concurrently with or after MCDB 210 or 240. Not open to freshmen. Special registration procedures apply; students must consult the instructor prior to the first week of classes.  SC

MCDB 261b, Systems Modeling in Biology  Thierry Emonet and Murat Acar
An introduction to quantitative methods in systems biology. Students will learn how to use mathematical modeling and systems analysis to address questions about the design principles of biological systems and to connect molecular mechanisms to behavior. Numerical and analytical modeling of static and dynamical processes in biological systems. This semester will contain instruction on Matlab and on writing, understanding, and solving differential equations. Topics will include switches, feedback, regulatory networks, cooperativity, and signal transduction. This class is intended as an introduction to the higher level course MCDB 361 Systems Biology. Prerequisite: PHYS 170 or equivalent or approval of instructor.  QR, SC

MCDB 290b, Microbiology  Christine Jacobs-Wagner and Carol Bascom-Slack
Cell structure of microorganisms, bacterial genetics, microbial evolution and diversity, microbial development, microbial interaction, chemotaxis and motility, gene regulation, microbial genomics, host defense systems, infectious diseases, viruses, and biological weapons. Prerequisites: BIOL 101 and 102, or a term of biochemistry, genetics, cell biology, or molecular biology.  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

*MCDB 300b / MB&B 200b, Biochemistry  Ronald Breaker and staff
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 / MB&B 251La, Laboratory for Biochemistry  William Konigsberg and staff
An introduction to current experimental methods in molecular biology. After or concurrently with MB&B 200 or 300. Limited enrollment. Requires preregistration by e-mail to Aruna Pawashe and William Konigsberg prior to the first week of classes.  SC

*MCDB 303Lb, Advanced Molecular Biology Laboratory  Maria Moreno and Kenneth Nelson
A laboratory course that provides advanced research skills in molecular biology. 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. For juniors who have completed MCDB 210L or 240L and are planning their senior research projects. No research laboratory experience required. Special registration procedures apply; interested students must contact the instructor and attend an organizational meeting.  SC

*MCDB 310a / BENG 350a, Physiological Systems  Mark Saltzman and staff
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 113 or 115, or PHYS 180 and 181; MCDB 121L, or BIOL 101 and 102.  SC

MCDB 315b, Biological Mechanisms of Reaction to Injury  Joseph Madri and staff
Human biology and disease as a manifestation of reaction to injury. Organ structure and function, cell injury, circulatory and inflammatory responses, disordered physiology, and neoplasia. Enrollment limited; preference to junior and senior majors in MCDB or MB&B. Prerequisite: MCDB 205, 300, or 310.  SC

MCDB 320b, 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. After a year of college-level chemistry; a course in physics is strongly recommended.  SC
**MCDB 321La**, Laboratory for Neurobiology  
Haig Keshishian and staff  
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 341La or b, Laboratory in Electron Microscopy*  
Barry Piekos  
Techniques in light and electron microscopy. Enrollment limited; preference to majors in MCDB or MB&B. Students must devote two to three laboratory hours per week in addition to the published meeting time. Students should contact the instructor prior to the first week of classes. After or concurrently with MCDB 205; prior laboratory experience strongly recommended.  
SC RP ½ Course cr

*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 must consult the instructor prior to the first week of classes.  
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. Prerequisite: MCDB 342L or permission of instructor. Enrollment limited. Special registration procedures apply; students must consult the instructor prior to the first week of classes.  
SC ½ Course cr

*MCDB 344La, Experimental Techniques in Cellular Biology*  
Joseph Wolenski  
An inquiry-based approach to research in cell and molecular biology, with emphasis on experimental strategies and techniques. Research is module-based and includes topics in gene expression, protein purification, and fluorescence microscopy. Methods include SDS-PAGE, immunoblots, column chromatography, mammalian cell culture, cell fractionation, cell transfection, and phase contrast and confocal microscopy. Prepares for MCDB 475, 485, or 495. 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 ¼ Course cr

*MCDB 345La, Experimental Strategies in Cellular Biology*  
Joseph Wolenski  
Continuation of MCDB 344L, with increased emphasis on experimental design and interpretation 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 experimental design. Prepares for MCDB 475, 485, or 495. Meets during March and April. Prerequisite: MCDB 344L. Special registration procedures apply; interested students must contact the instructor at least eighteen months in advance.  
SC ¼ Course cr

*MCDB 370b*, Biotechnology  
Kenneth Nelson and staff  
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  
Frederick Sigworth and 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  
Tian Xu and staff  
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 200 or equivalent.  
SC

*MCDB 430a*, Biology of the Immune System  
Akiko Iwasaki and staff  
SC

*MCDB 435a, Landmark Papers in Cell Biology*  
Joel Rosenbaum  
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. Weekly discussion by all participants required. 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 440b*, Brain Development and Plasticity  Weimin Zhong and Sreeganga Chandra
Recent advances in scientific understanding of brain development and plasticity, including neuronal determination, axon guidance, synaptogenesis, and developmental plasticity. Prerequisites: BIOL 101, 102, and 103, or equivalent performance on the corresponding biological sciences placement examinations; MCDB 320 or permission of instructor.  SC

MCDB 452b / MB&B 452b, Bioinformatics: Practical Application of Simulation and Data Mining  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 470a or b, Tutorial in Molecular, Cellular, and Developmental Biology  Douglas Kankel
Individual or small-group study for qualified students who wish to investigate a broad area of experimental biology not presently covered by regular courses. A student must be sponsored by a Yale faculty member, who sets the requirements. The course must include one or more written examinations and/or a term paper. Intended to be a supplementary course and, therefore, to have weekly or biweekly discussion meetings between the student and the sponsoring faculty member. To register, the student must prepare a form (available on the departmental Web site (http://www.biology.yale.edu/undergrad/forms.html) and on the course site on Classes*v2 (https://classesv2.yale.edu/portal)) and a written plan of study with bibliography, approved by the faculty research adviser. The form and proposal must be uploaded to Classes*v2 (https://classesv2.yale.edu/portal) by the end of the second week of classes. The final paper is due in the hands of the sponsoring faculty member, with a copy to the course instructor, by the last day of classes. In special cases, with approval of the director of undergraduate studies, this course may be elected for more than one term, but only one term may count as an elective toward the major. Fulfills the senior requirement for the B.A. degree if taken in the senior year.

*MCDB 475a or b, Research  Douglas Kankel and staff
Research projects under faculty supervision, ordinarily taken to fulfill the senior requirement. This course may be taken before the senior year, but it cannot substitute for other requirements. Students are expected to spend approximately ten hours per week in the laboratory. To register, the student must prepare a form (available on the departmental Web site (http://www.biology.yale.edu/undergrad/forms.html) and on the course site on Classes*v2 (https://classesv2.yale.edu/portal)) and a written plan of study with bibliography, approved by the faculty research adviser. The form and proposal must be uploaded to Classes*v2 (https://classesv2.yale.edu/portal) 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 to the course instructor, by the last day of classes. Seniors taking this course to fulfill the senior requirement must give an oral presentation of their research at the end of the term. 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 MCD 486b, Research in Molecular, Cellular, and Developmental Biology  Douglas Kankel and staff
Individual two-term laboratory research projects under the supervision of a faculty member. 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 on the departmental Web site (http://www.biology.yale.edu/undergrad/forms.html) and on the course site on Classes*v2 (https://classesv2.yale.edu/portal). 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, Intensive Research in Molecular, Cellular, and Developmental Biology  Douglas Kankel and staff
Qualified students may undertake directed research in some field of biology during the senior year. Before registering for this course, the student must be accepted for a research project 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 on the departmental Web site (http://www.biology.yale.edu/undergrad/forms.html) and on the course site on Classes*v2 (https://classesv2.yale.edu/portal). 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