

BASIC UNDERGRADUATE
CURRICULUM GUIDE
SEPTEMBER 2014



UNIVERSITY of
ROCHESTER
BIOMEDICAL ENGINEERING

Taimi Marple
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BME ADVISORS

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BME PRIMARY FACULTY

Chair of the Department

Richard E. Waugh, Ph.D. (Duke) *Professor of Biomedical Engineering, of Pharmacology and Physiology, of Biochemistry and Biophysics, and of Mechanical Engineering*
Research Area - Mechanical and thermodynamic properties of biological membranes; cellular mechanics and function of cytoskeletal proteins

Hani Awad, Ph.D. (Cincinnati) *Professor of Biomedical Engineering and of Orthopaedics and Center for Musculoskeletal Research*

Research Area - Biomechanics of connective tissues, functional biomaterials of connective tissue, physicochemical regulation of engineered tissues, tissue engineering bioreactors, differentiation of stem cells, skeletal phenotyping of genetically altered mice

Danielle Benoit, Ph.D. (Colorado) *Assistant Professor of Biomedical Engineering and Chemical Engineering; and Center for Musculoskeletal Research*

Research Area - Tissue engineering, polymers, scaffolds, stem cells, musculoskeletal tissues, biomaterials, drug delivery, siRNA

Edward Brown III, Ph.D. (Cornell) *Associate Professor of Biomedical Engineering*

Research Area - Multi-photon microscopy for studies of vasculogenesis and tumor diagnostics

Mark Buckley, Ph.D. (Cornell) *Assistant Professor of Biomedical Engineering; and Center for Musculoskeletal Research*

Research Area – Soft biological tissue mechanics, viscoelasticity, tendon healing

Laurel Carney, Ph.D. (Wisconsin) *Professor of Biomedical Engineering and of Neurobiology and Anatomy*

Research Area – Auditory Neuroscience; neurophysiological, behavioral, and computational studies of hearing; signal processing for hearing aids

Regine Choe, Ph.D. (U Penn) *Assistant Professor of Biomedical Engineering*

Research Area – Development and improvement of diffuse optical methods based on near-infrared light illumination for detection and therapy monitoring of disease, including breast cancer.

Diane Dalecki, Ph.D. (Rochester) *Professor of Biomedical Engineering and of Electrical and Computer Engineering, and Director of The Rochester Center for Biomedical Ultrasound*

Research Area - Biomedical ultrasound, acoustics, lithotripsy, biological effects of ultrasound

Greg Gdowski, Ph.D. (Boston U) *Associate Professor of Biomedical Engineering and Executive Director of the Center for Medical Technology & Innovation*

Research Area – Sensory signals of the vestibular system with regard to control and coordination of reflexive and voluntary movements, particularly those that reorient the head to the body

Amy Lerner, Ph.D. (Michigan) *Associate Professor of Biomedical Engineering and of Mechanical Engineering and Academic Director of the Center for Medical Technology & Innovation.*

Research Area - Orthopedic biomechanics, bone growth and development, cartilage mechanics, medical image-based finite element modeling, knee biomechanics

Anne E. Luebke, Ph.D. (Johns Hopkins) *Associate Professor of Biomedical Engineering and of Neurobiology and Anatomy*

Research Area - Gene transfer to the cochlear, stem cell transfection, molecular biology of auditory efferent system receptors

Stephen McAleavey, Ph.D. (Rochester) *Associate Professor of Biomedical Engineering*
Research Area – Biomedical ultrasound, medical imaging, image-guided therapy, applications of time-delay estimation

James McGrath, Ph.D. (MIT) *Professor of Biomedical Engineering*
Research Area - Cell mechanics and motility, endothelial monolayer function, actin-based motility of pathogens

Jong-Hoon Nam, Ph.D. (VA Tech) *Assistant Professor of Mechanical Engineering and Biomedical Engineering*
Research Area – Function of inner ear sensory systems, focusing on the mechanical interaction between the inner ear sensory cells and their surrounding structures, combining computational and experimental methods.

Scott Seidman, Ph.D. (Case Western) *Associate Professor of Biomedical Engineering and of Neurobiology and Anatomy*
Research Area - Neural control and mathematical modeling of reflex eye movements, physiological control systems

Axel Wismüeller, M.D., Ph.D., (Technical University, Munich, Germany), *Professor of Biomedical Engineering and of Imaging Sciences*
Research Area – Development of novel intuitively intelligible computational visualization methods for the exploratory analysis of high-dimensional data from biomedical imaging.

JOINT APPOINTMENTS WITH BIOMEDICAL ENGINEERING

Joan Adamo, Ph.D. (Cornell University) *Adjunct Assistant Professor of Biomedical Engineering*

Andrew Berger, Ph.D. (MIT) *Associate Professor of Optics and of Biomedical engineering*

David Borkholder, Ph.D. (Stanford) *Assistant Professor, Electrical Engineering, Rochester Institute of Technology, and Adjunct Associate Professor of Biomedical Engineering*

Ankur Chandra, M.D. (Case Western) *Associate Professor of Surgery, and of Biomedical Engineering*

Patricia R Batchelor Chess, M.D. (Columbia) *Professor of Pediatrics and of Biomedical Engineering*

Alfred Clark, Jr., Ph.D. (MIT) *Professor of Mechanical Engineering, of Mathematics, and of Biomedical Engineering*

Robert Clark, Ph.D. (Virginia Polytechnic Institute) *Professor of Mechanical Engineering and of Biomedical Engineering*

Benjamin Crane, M.D., Ph.D. (UCLA) *Associate Professor of Neurobiology and Anatomy and of Biomedical Engineering*

David Dean, Ph.D. (UC Berkeley) *Professor of Pediatrics and Biomedical Engineering*

Gregory DeAngelis, Ph.D. (California, Berkeley) *Professor of Brain and Cognitive Sciences, of Biomedical Engineering, of Neurobiology and Anatomy and in the Center for Visual Science*

Lisa A. DeLouise, Ph.D. (Pennsylvania State) *Associate Professor of Dermatology and of Biomedical Engineering*

Virkrim Dogra, Ph.D. (University of Madras, India) *Professor of Radiology and Biomedical Engineering*

Marvin Doyley, Ph.D. (University of London) *Associate Professor of Electrical and of Computer Engineering and of Biomedical Engineering*

Thomas Foster, Ph.D. (Rochester) *Professor of Imaging Sciences, and of Biomedical Engineering*

Keigi Fujiwara, Ph.D. (U Penn) *Professor of Medicine and of Biomedical Engineering*

Angela Glading, Ph.D. (Pittsburgh) *Assistant Professor of Pharmacology and Physiology*

Sheryl Gracewski, Ph.D. (California) *Professor of Mechanical Engineering and of Biomedical Engineering*

Denise Hocking, Ph.D. (Albany) *Associate Professor of Pharmacology and Physiology and of Biomedical Engineering*

Jennifer J. Hunter, Ph.D. (Waterloo) *Assistant Professor of Ophthalmology and Biomedical Engineering*

Luiz Meirelles, Ph.D. (University of Gothenburg) *Assistant Professor of Dentistry and Biomedical Engineering*

Ben Miller, Ph.D. (Stafford) *Professor of Dermatology, of Biochemistry and Biophysics, and of Biomedical Engineering*

Duncan T. Moore, Ph.D. (Rochester) *Professor of Optics and of Biomedical Engineering and Rudolph and Hilda Kingslake Professor of Optical Engineering Science*

Maiken Nedergaard, M.D. (University of Copenhagen) *Professor of Neurosurgery and of Biomedical Engineering*

Ruola Ning, Ph.D. (Utah) *Professor of Radiology and of Electrical and Computer Engineering*

Gary Paige, M.D., Ph.D. (Chicago) *Kilian J. and Caroline F. Schmitt Professor of Neurobiology and Anatomy, of Ophthalmology, and of Biomedical Engineering*

Kevin J. Parker, Ph.D. (MIT) *Professor of Electrical and Computer Engineering, of Radiology and of Biomedical Engineering, Dean Emeritus, Hajim School of Engineering and Applied Sciences*

Renato Perucchio, D. Engr. (Pisa, Italy) *Professor of Mechanical Engineering and of Biomedical Engineering, and Associate Professor of Pediatrics*

J. Edward Puzas, Ph.D. (Rochester) *Donald and Mary Clark Professor of Orthopaedics and of Biomedical Engineering*

Janick Rolland, Ph.D. (University of Arizona) *Professor of Optics and of Biomedical Engineering*

Deborah Rubens, M.D. (Rochester) *Professor of Imaging Sciences; Associate Chair of Imaging Sciences*

Ingrid H. Sarelius, Ph.D. (Auckland, New Zealand) *Professor of Pharmacology and Physiology and of Biomedical Engineering*

Michael C. Schell, Ph.D. (Wisconsin, Madison) *Professor of Radiation Oncology and of Biomedical Engineering*

Edward M. Schwarz, Ph.D. (Albert Einstein College of Medicine) *Professor of Orthopaedics, of Microbiology and Immunology, of Urology, of Medicine, of Pathology and Laboratory Medicine, and of Biomedical Engineering*

Denham S. Ward, M.D. (Miami) *Professor of Anesthesiology and of Biomedical Engineering*

David R. Williams, Ph.D. (California, San Diego) *Dean for Research in Arts, Sciences, and Engineering, William G. Allyn Professor of Medical Optics, Director of the Center for Visual Sciences, Professor of Optics, of Ophthalmology, of Biomedical Engineering, and of Brain and Cognitive Sciences*

J. H. David Wu, Ph.D. (MIT) *Professor of Chemical Engineering, of Microbiology and Immunology and of Biomedical Engineering*

Geunyoung Yoon, Ph.D. (Osaka) *Associate Professor of Ophthalmology, of Biomedical Engineering, and in the Center for Visual Science*

James M. Zavislan, Ph.D. (Rochester) *Associate Professor of Optics, of Dermatology, of Ophthalmology, and of Biomedical Engineering*

Jianhui Zhong, Ph.D. (Brown) *Professor of Radiology and of Biomedical Engineering and of Physics*

AFFILIATED FACULTY

Edwin Carstensen, Ph.D. (University of Pennsylvania) *Arthur Gould Yates Professor Emeritus of Engineering and Senior Scientist in Electrical and Computer Engineering*

Jean-Philippe Couderc, Ph.D. (National Institute of Applied Science, Lyon, France) *Associate Professor of Medicine*

Barbara J. Davis, Ph.D. (SUNY Upstate) *Associate Professor of Neurobiology and Anatomy*

Arthur Moss, M.D. (Harvard) *Professor of Medicine, Cardiology Division*

Alice Pentland, M.D. (Michigan) *James H. Sterner Professor of Dermatology; Medical Director of Center for Future Health and Chair of Dermatology*

Deborah Rubens, M.D. (Rochester) *Professor of Imaging Sciences; Associate Chair of Imaging Sciences*

Peter G. Shrager, Ph.D. (California, Berkeley) *Professor of Neurobiology and Anatomy*

INTRODUCTION

Biomedical Engineering (BME) involves the application of engineering science and technology to solve problems in biology and medicine. This broad area offers many career opportunities, ranging in scope from advanced research to engineering practice in industrial or clinical settings. The Department of Biomedical Engineering, in conjunction with strong academic programs in the basic sciences and other engineering disciplines at the University of Rochester, offers outstanding training in this rapidly growing field.

B.S. IN BIOMEDICAL ENGINEERING

The Bachelor of Science degree program in biomedical engineering at the University of Rochester is accredited by the Engineering Accreditation Commission of ABET, <http://abet.org>, and has been accredited since 2001. Our curriculum emphasizes fundamental engineering and design principles taught in the context of current problems in medicine and biology. A series of nine core courses required of all BME students provides a solid foundation in engineering principles relevant to biomedical engineering practice. To ensure in-depth training in engineering, students are required to complete a sequence of four engineering courses in a focus area of biomedical engineering. These areas of concentration are Biomechanics, Biosignals and Biosystems, Cell and Tissue Engineering, and Medical Optics. The program is capped with a biomedical engineering senior design course required for all students. This program requires a total of 130 credit hours, including a minimum of 50 credit hours devoted to mathematics and natural sciences and a minimum of 51 credit hours devoted to engineering.

The Undergraduate Program

The interdisciplinary nature of biomedical engineering requires expertise in both the biological and engineering sciences. The University of Rochester offers several avenues of academic study in biomedical engineering, each of which can be structured to satisfy pre-medical or pre-dental requirements. The University of Rochester offers B.S., M.S. and Ph.D. programs in biomedical engineering. The Minor in biomedical engineering (24 credits) provides opportunities for students majoring in other disciplines to obtain substantive exposure to the field of biomedical engineering. Minor requirements are listed below, and on the BME website: <http://www.urmc.rochester.edu/bme/>

DEPARTMENTAL MISSION AND PROGRAM EDUCATIONAL OBJECTIVES

Mission

Discover, create, and educate to engineer ever better solutions in biomedical research and health care.

Undergraduate Program Educational Objectives

The overall educational objective of our program is to develop effective practitioners in biomedical engineering and associated fields. We expect that our graduates will contribute to the advancement of their chosen field, while remaining mindful of the ethical and social implications of their work. They will confidently apply knowledge in the basic sciences, mathematics, engineering analysis, and design to address problems in medicine and biology. In keeping with the continuously evolving nature of the field of biomedical engineering, we expect that our alumni will effectively communicate, engage in lifelong learning, and that many of them, inspired by research experiences as undergraduates, will continue their education in advanced degree programs.

BME CURRICULUM AND REQUIREMENTS

Basic Science & Math Courses (38 credit hours)

Nine courses in natural sciences and mathematics divided as follows:

Four Math courses - MTH 161, 162, 163 **or** 165, 164

(MTH 141, 142, & 143 are equivalent to MTH 161 & 162)

Two Chemistry courses - CHM 131 and CHM 132 (5 credits each)

Two Physics courses - PHY 121, 122

One Biology course - BIO 110

Core BME Courses (35 credit hours)

The curriculum features a series of core BME courses that aims to provide students with a breadth of knowledge and skills in the field of biomedical engineering. The following courses form the BME Core. (See Appendix for course descriptions)

BME 101/EAS101 - Introduction to Biomedical Engineering

BME 201 - Fundamentals of Biomechanics

BME 201P - MATLAB for Biomechanics (1 credit)

BME 210 - Biosystems and Circuits

BME 221 - Biomedical Computation & Statistics

BME 230 - Biomedical Signals, Systems & Imaging

BME 245 - Biomaterials

BME 260 - Quantitative Physiology with lab

BME 295 - BME Design Seminar (2 credits)

BME 296 - BME Senior Design

Basic Science Electives (12 credit hours)

All students must complete at least three additional courses (at least 12 credit hours) in the basic sciences beyond the required introductory biology (BIO 110), chemistry (CHM 131 & CHM 132), and physics (PHY 121/141 & PHY 122/142) courses. Any biology, microbiology, neuroscience, chemistry, or physics course with number greater than 109 may be used to fulfill this requirement (excluding BIO 111, 112, 113). At least one of these courses must have a laboratory component. At least two courses must be life science courses (i.e., biology, microbiology, neuroscience). Students are encouraged to choose their basic science electives to complement their BME concentration area. Independent study courses cannot be used to satisfy this requirement.

** If a student is a life science minor, they will be required to take only (1) life science course for their Basic Science Elective requirement.

Some recommendations for Basic Science Elective sequences are provided below.

Example 1:

BME 258 - Human Anatomy (4 credits, spring - includes laboratory component)

BIO 204 – Mammalian Physiology (4 credits, spring - includes laboratory component)

PHY 123 – Modern Physics (4 credits, spring - includes laboratory component)

*Example 2: (This sequence is **required** for students in the Cell & Tissue Engineering Concentration)*

CHM 203 – Organic Chemistry I (4 credits, fall) with CHM 207 – Organic Chem. Lab I (1 credit, fall)

BIO 250 – Biochemistry (4 credits, spring) with BIO 151 – Intro to Biochemistry Lab (1 credit, spring)

BIO 210 – Molecular Cell Biology (4 credits, fall, no laboratory component)

Example 3:

CHM 203 – Organic Chemistry I (4 credits, fall) with CHM 207 – Organic Chemistry Lab I (1 credit, fall)

BIO 250 – Biochemistry (4 credits, spring) with BIO 151 – Intro to Biochemistry Lab (1 credit, spring)

BIO 190 – Principles of Genetics (4 credits, fall) with BIO 198L – Genetics Lab (1 credit, fall)

Example 4:

BME 258 – Human Anatomy 4 credits, spring - includes laboratory component)

NSC 201 – Basic Neurobiology (4 credits, fall - no laboratory component)

NSC 245 – Sensory & Motor Neuroscience (4 credits, spring)

Example 5: (Pre-Med: these requirements include two semesters of organic chemistry with laboratories and two semesters of biology with laboratories. Thus, students will need to use at least one free elective to fulfill pre-medical science requirements.

CHM 203 – Organic Chemistry I (4 credits, fall) with CHM 207 – Organic Chemistry Lab I (1 credit, fall)

BIO 204 – Mammalian Physiology (4 credits, spring, includes laboratory component)

BIO 190 – Principles of Genetics (4 credits, fall) with BIO 198L – Genetics Lab (1 credit, fall)

Technical Elective (4 credit hours)

The Technical Elective requirement is satisfied by BME101, EAS102, EAS103, EAS104, or by a course from the current list of BME-approved technical electives. Students who do not take BME101 must take a substitute technical elective. Suitable courses must have significant engineering design, analysis, synthesis, or technical components. The following courses *may not* be used towards the technical elective: BME258, ECE111, ECE113, ECE399, CHE150, CHE211, CHE290, ME120, ME163, ME164, ME202, ME211, OPT287, all EAS courses except those listed above. Classes that are primarily mathematics or science courses *may not* be used. Classes that are equivalent to core or concentration courses *are disallowed*, e.g. ME225 Fluid Mechanics cannot be used as a technical elective when CHE243 Fluid Dynamics has already been taken to fulfill the concentration requirements. Courses that are cross-listed with non-HSEAS departments (e.g. CHE277/AAS277) must be taken under the HSEAS registration.

Cluster and Humanities & Social Sciences (H/SS) (16 credit hours)

All BME majors must complete a total of **four** courses in humanities and/or social sciences. Three of these courses must constitute an approved Cluster in Humanities or Social Sciences and must be passed with a 2.0 average or better. See the Cluster Search Engine on the UR website to review courses and descriptions: <https://secure1.rochester.edu/registrar/CSE/index.php>

The fourth course can be chosen from any recognized Humanities or Social Science field. Courses in the business field may not be used to satisfy the additional course requirement.

**A second major or minor in a Humanities or Social Science (H/SS) area will also satisfy the cluster and additional H/SS course requirement.

No computer courses offered in humanities or social science fields may be used as a H/SS distribution course.

Primary Writing Requirement (4 credit hours)

The Primary Writing Requirement must be satisfied before admission to the program. (WRT 105 - Reason and Writing) See the website:

<http://www.rochester.edu/College/CCAS/AdviserHandbook/PrimWrReq.html>.

Free Electives (8 credit hours)

Any courses taken at the UR, AP courses or transfer courses

Upper Level Writing Requirement

Significant writing experience in one's discipline is an important adjunct to the technical material one learns. As of 7/01, the courses that fulfill the University's Upper Level Writing Requirement by placing significant weight on the effectiveness of written communication are: BME 221, BME 230, BME 260, BME 296, and any upper-level BME course.

BME Concentration Courses (16 credit hours)

Students choose to concentrate in one of four BME specialty areas. Four engineering courses are required to form a sequence in one of the following areas: Biosignals & Biosystems, Biomechanics, Cell & Tissue Engineering, or Medical Optics. Each concentration includes an upper level BME course in the specialty area. Courses for each concentration and example course schedules are given below.

Biosignals & Biosystems

ECE 230 - Electromagnetic Waves

ECE 221 - Electronic Devices & Circuits **or** BME 228 Physiological Control Systems

ECE 246 - Digital Signal Processing

Upper Level BME: e.g. BME 251 - Biomedical Ultrasound, ECE 452 - Medical Imaging, BME 218

Introduction to Neuroengineering

Biomechanics

ME 226 - Introduction to Solid Mechanics

ME 225 - Introduction to Fluid Dynamics

ME 123 - Thermodynamics

Upper Level BME: e.g. BME 283 - Biosolid Mechanics or BME 212 Viscoelasticity in Biological Tissues

Cell & Tissue Engineering

CHE 243 - Fluid Dynamics

CHE 244 - Heat & Mass Transfer

CHE 225 - Thermodynamics

Upper Level BME: e.g. BME 262 Cell & Tissue Engineering

Medical Optics

BME 270 - Biomedical Microscopy

OPT 241 - Geometrical Optics

OPT 261 - Interference & Diffraction

Upper Level BME: e.g. OPT 276 -Biomedical Optics or BME 255 - Translational Biomedical Optics

FIRST & SECOND YEAR **FOR ALL BME STUDENTS**

1st Year

Fall

MTH 161*-Calculus IA
CHM 131-Chem. Concepts I (lab)
EAS/BME 101-Intro. to BME (lab) (*Core*)
Primary Writing **or** H/SS

Spring

MTH 162*-Calculus IIA
CHM132 -Chem. Concepts II (lab)
PHY 121-Mechanics (lab)
H/SS **or** Primary Writing

2nd Year

Fall

MTH 163 **or** 165**-Differential Equations
PHY 122-Electricity & Magnetism (lab)
BIO 110-Principles of Biology I
BME 201-Fund. of Biomechanics (*Core*)
BME 201P – MATLAB for Biomechanics - 1 cr.

Spring

MTH 164-Multidimensional Calculus
Basic Science Elective or 1st concentration course***
BME 210-Biosystems & Circuits (lab) (*Core*)
H/SS

*An alternative to the MTH 161 and 162 sequence is the MTH 141, 142 and 143 sequence. Careful attention must be paid to the effects of this longer sequence, including the possible need to take a course in the summer following the first year. MTH171 series can be used to fulfill the Math requirements

** Either MTH 163 or 165 will satisfy the math requirements of the BME program.

NOTE:* The following courses are required as concentration courses in the Spring of Sophomore year:**
Cell & Tissue - CHE243; Biomechanics - ME226; Medical Optics – BME270

Humanities, Social Sciences, and Elective courses can be taken in any semester.

THIRD & FOURTH YEARS

CELL & TISSUE ENGINEERING

3rd Year

Fall

Elective
CHE 244 - Heat & Mass Transfer
BME 230 – Signals, Systems & Imaging (*Core*)
CHM 203-Orgo I & 207 Lab

Spring

BME 245 – Biomaterials (*Core*)
H/SS
BME 221 - Biomedical Computation & Statistics (*Core*)
BIO 250-Biochemistry & 151 Lab (lab is optional)

4th Year

Fall

BME 260 - Quantitative Physiology (*Core*)
BME 295 - Design Seminar (2 cr.) (*Core*)
BIO 210 - Molecular Cell Biology
CHE 225-Thermodynamics
H/SS

Spring

BME 296 - Senior Design (*Core*)
Upper Level BME
Elective
Elective

BIOSIGNALS & BIOSYSTEMS

3rd Year

Fall

ECE 221-Electronic Devices & Circuits or
BME 228- Physiological Control Systems
BME 230 –Signals, Systems, & Imaging (*Core*)
Basic Science Elective
H/SS

Spring

BME 245 – Biomaterials (*Core*)
H/SS
BME 221- Biomedical Computation & Statistics (*Core*)
Basic Science Elective

4th Year

Fall

BME 260 - Quantitative Physiology (*Core*)
BME 295 - Design Seminar (2 cr.) (*Core*)
Upper Level BME
ECE246 - Digital Signal Processing
ECE230 – Electromagnetic Waves

Spring

BME 296 - Senior Design (*Core*)
Elective
Elective
Elective

BIOMECHANICS

3rd Year

Fall

Elective
H/SS
BME 230 - Signals, Systems, & Imaging (*Core*)
Basic Science Elective

Spring

ME 123 - Thermodynamics
Basic Science Elective
BME 221 - Biomedical Computation & Statistics (*Core*)
BME 245 – Biomaterials (*Core*)

4th Year

Fall

BME 260 - Quantitative Physiology(*Core*)
BME 295 - Design Seminar (2 cr.) (*Core*)
ME 225 – Introduction to Fluid Dynamics
Upper Level BME or Elective
Basic Science Elective

Spring

BME 296 - Senior Design (*Core*)
Elective or Upper Level BME
H/SS
Elective

MEDICAL OPTICS

3rd Year

Fall

OPT 241 - Geometrical Optics
BME 230–Signals, Systems, & Imaging (lab)(*Core*)
Basic Science Elective
Basic Science Elective

Spring

H/SS
OPT 261 – Interference & Diffraction
BME 221 - Biomedical Computation & Statistics (*Core*)
BME 245 – Biomaterials (*Core*)

4th Year

Fall

BME 260 - Quantitative Physiology (*Core*)
BME 295 - Design Seminar (2 cr.) (*Core*)
Upper Level BME or Elective
Basic Science Elective
H/SS

Spring

BME 296 - Senior Design (*Core*)
Elective or Upper Level BME
Elective
Elective

ADMISSION REQUIREMENTS

Students wishing to major in Biomedical Engineering must file a completed BME Curriculum Planning form ordinarily during the fourth semester of study. This form, along with a Declaration of Major Approval form, constitutes application to the upper-division BME program.

To be considered for admission to the biomedical engineering major a student must have taken courses in the first two years to enable a program of study that satisfies the requirements of the program and that can be completed in a total of four years.

The minimum requirements for admission to the BME program are

- satisfactory completion of BME 101 (by the end of the sophomore year) (transfer students will substitute another upper level BME course)
- two engineering courses (usually BME 201/201P, BME 210)
- a minimum ADMIT GPA of 2.30 in these four courses (BME101, BME201, BME201P, & BME 210)
- satisfactory completion of the basic science and math requirements
- a minimum overall cumulative GPA of 2.0
- satisfactory completion of the University primary writing requirement (WRT105)
- completion of BME Career Planning Form

A BME Career Planning form must accompany the major declaration forms. The university requirement that a student should be free of academic probation also applies. The submitted career plan, though never binding, is very useful in helping students focus their interests within the field of biomedical engineering. Before preparing and submitting a career plan, each student should study available online and written material and then discuss the alternatives fully with his or her faculty advisor or with other faculty. The Curriculum Planning Form, approved and signed by the student's faculty advisor, will then be attached to a Declaration of Major Approval form and submitted to the School of Engineering and Applied Sciences (SEAS) Dean's Office.

Under special circumstances, such as transfer from another institution or a change of intended major in the early years of study, students may not complete all the requirements for admission by the end of the sophomore year. Students in such a situation may qualify for **conditional admission** by submitting a form, available from the BME Undergraduate Office - Goergen 206, to the BME Undergraduate Committee along with an up-to-date BME Curriculum Planning Form. The application must present a realistic plan, approved by the student's advisor, for completion of all BME program admission requirements within one year. Failure to meet the requirements within one year will result in removal from the major.

Only the Administrative Committee of the School of Engineering and Applied Sciences can make exceptions from the general degree requirements published in the Official Bulletin of the University. Petition forms for Administrative Committee consideration may be obtained from the BME Undergraduate Office - Goergen 206.

GRADUATION REQUIREMENTS

For graduation, biomedical engineering majors must satisfactorily complete all course requirements consisting of a total of 129 credits with an overall cumulative grade point average of 2.00.

TRANSFER CREDITS

Prior approval is required if a student wishes to take a course at another institution to satisfy a BME degree requirement. A Course Approval form is available in the BME Undergraduate Office-Goergen

206 or in Lattimore 312. Students are strongly advised to seek the advice of their advisor before registering for a course at another institution.

MINOR IN BIOMEDICAL ENGINEERING

The biomedical engineering minor provides substantive exposure to the biological and engineering sciences and gives students a basic perspective on the complex structure and function of living systems and their analysis by physical and engineering principles. The minor is available to students in all majors, but engineering and biology students find it easier to complete these requirements. Students may not use more than two of the courses required for the BME minor to also satisfy requirements in their major (including technical electives). All students that propose a minor in BME must fulfill the basic math requirements (MTH161, MTH162, MTH165 or MTH141, MTH142, MTH143 or these in combination with Math AP credit). Contact Professor Stephen McAleavey for Minor Declaration approval.

Biological Science Courses (8 credit hours)

Students must complete two life science courses (i.e., biology, microbiology, neuroscience). Students can use one of the following: BIO110, BIO112 or AP Biology, plus one other Life Science to meet the two life science course requirement.

Biomedical Engineering Introductory Course (4 credit hours)

BME101 (4.0 credits) is a freshman or sophomore course utilizing the spectrum of examples of BME applications to introduce the scope of the discipline and its range of significance. Faculty advisors have the flexibility of substituting four credits of another BME-related course.

Engineering Courses (12 credit hours)

Choose three engineering courses, *two of which must be BME courses*, including any 400-level BME courses or cross-listed courses.

Note: Students are warned to confirm that all prerequisites for the courses below are fulfilled

Examples

- BME 201/201P Fundamentals of Biomechanics/MATLAB for Bioengineers
- BME 212 Viscoelasticity in Biological Tissues
- BME 218 Introduction to Neuroengineering
- BME 221 Biomedical Computation
- BME 228 Physiological Control Systems
- BME 230 Biomedical Signals and Measurements
- BME 245 Biomaterials
- BME 251 Biomedical Ultrasound
- BME 255 Translational Biomedical Optics
- BME 260 Quantitative Physiology
- BME 262 Cell and Tissue Engineering
- BME 267 Models and Simulations of Biomedical Systems
- BME 270 Biomedical Microscopy
- BME 283 Biosolid Mechanics
- BME 391 Independent Study
- CHE 243 or ME 225 Fluid Dynamics/Introduction to Fluid Dynamics
- CHE 259 Transport Phenomena in Biological Systems
- ECE 210 or 113 Circuits for Scientists and Engineers/Circuits and Signals
- ME 226 Introduction to Solid Mechanics
- OPT 241 Geometrical Optics

FIVE-YEAR BS/MS PROGRAM (+1 Program)

BME majors contemplating graduate work should consider the five-year, BS/MS program offered by the Department of [Biomedical Engineering](#). This program provides the opportunity for a smooth transition between undergraduate and graduate study. Program enrollment is competitive and students may apply for admission during their senior year. This program offers the chance for more advanced study and the completion of a course-work masters degree in one year. (Note that a thesis Masters is expected to take one and a half to two years.) Partial tuition scholarships are available for the Masters program. All full-time MS students are expected to serve as teaching assistants for one semester. Another MS option is the Center for [Medical Technology & Innovation \(CMTI-MS\)](#) option. This program intends to directly effect improvement in patient care and outcomes while promoting a unique education in both clinical care and bioengineering design. It includes a period of clinical immersion followed by a one-year, in-depth design experience.

Students should consult the *UR Graduate Studies Official Bulletin* for the MS degree requirements and they should meet with a faculty member or the Graduate Coordinator (Goergen 207) to develop an integrated BS/MS program of study (required for admission). *UR Graduate Studies Official Bulletin* is available at: www.rochester.edu/GradBulletin

TAKE FIVE SCHOLAR PROGRAM

The Take Five Scholar Program provides University of Rochester students with opportunities to explore additional disciplines and courses that might not otherwise be available to them within the four year degree path. Accepted students will be granted one or two tuition-free semesters to take courses in addition to those needed to complete their degree. Students may apply from the time they have been formally accepted into their major through the first semester of their senior year. Transfer students must have completed one full semester at the University before applying.

Additional information at: <http://www.rochester.edu/college/CCAS/students/opportunities/takefive/>

INTERNSHIPS AND INDUSTRY PRACTICUM

BME majors are strongly encouraged to participate in internships with local or nationally based engineering firms or research institutions. Only in a few cases can internship experiences be used for academic credit. Students who wish to obtain such credit for an internship must obtain prior approval from the BME Undergraduate Committee.

The Industry Practicum program is a way to gain valuable work experience. A student in this program takes one semester, and the summer preceding or following that semester to work for a company. Academic credit is not granted, but the work experience and references obtained are valuable in later job searching. Typically, graduation is delayed by one semester, but some students with Advanced Placement credit or summer classes can graduate on time. Additional information, including example programs, is available from the SEAS Office or Career and Internship Center in Dewey Hall, 4th floor, www.rochester.edu/careercenter/

STUDY ABROAD

The Hajim School of Engineering highly recommends engineering students study abroad and aims to have ~25% of all UR engineering students participate. If you are considering spending a semester, a year or summer in another country, please check out the UR website to explore the opportunities available to you. You will find numerous resources to help you plan your studies overseas at:

<http://www.rochester.edu/College/abroad/programs/index.html>

Visit the Center for Study Abroad and Interdepartmental Programs as you plan. The Center is located in Lattimore 206, and is there to help you, to share your excitement, and to assist you in making it all work. Additional information at: www.rochester.edu/College/abroad/

Biomedical Engineering faculty dedicated to Study Abroad are Professors Anne Luebke and Scott Seidman.

PRE-MEDICAL PROGRAM

BME students interested in a pre-med program are urged to obtain related materials from the Health Professions Advisors at the College Center for Advising Services, Lattimore 312. It is essential that such students begin program planning very early and involve both their BME advisor and the Health Professions Advisor.

Additional information at: <http://www.rochester.edu/college/ccas/health/academics/pre-req.html>

All of the courses usually required for admission to medical school are readily accommodated within the B.S. in BME curricular requirements. These include two semesters of general physics, two semesters of general chemistry, two semesters of Organic Chemistry with labs, two semesters of biology with labs, two semesters of math, and two semesters of English.

GEAR PROGRAM

Incoming students can apply for the GEAR program when they first apply to the University of Rochester. The GEAR program provides selected students with an assurance of admission into one of seven engineering master's programs at the University of Rochester's Edmund A. Hajim School of Engineering and Applied Sciences: biomedical engineering, chemical engineering, computer science, electrical and computer engineering, materials science, mechanical engineering, optics, alternative energy, technical entrepreneurship and management (TEAM). GEAR students receive a 50 percent tuition award in their fifth year of study in the form of a teaching assistantship. To remain eligible, GEAR students are required to maintain a 3.3 GPA through the first seven semesters (3.5 for optics). Applicants for this program will have demonstrated strong aptitude for engineering throughout their high school academic and co-curricular activities. Please visit GEAR Admissions at: <http://enrollment.rochester.edu/admissions/CAPs/GEAR/>

KAUFFMAN ENTREPRENEURIAL YEAR (KEY) PROGRAM

The University of Rochester defines entrepreneurship as "transforming an idea into an enterprise that generates value," implying that the enterprise outlives the creator and that it positively affects others. Qualified students may propose to devote as much as an entire academic year to internships, special projects, business plan development, research into various facets of entrepreneurship, or analysis of how culture and public policy influence entrepreneurial activity. Students may apply from the time that they have been accepted into a major through the second semester of their senior year. Participation is open to all undergraduates in the College and the Eastman School of Music with the following exceptions:

- * Transfer students may not apply during their first semester at the University
- * Take Five Scholars may not apply for the KEY Program

Applications are available at each of several information sessions held each semester, at the Academic Services Counter outside Lattimore 312.

Additional information at: www.rochester.edu/entrepreneurship/programs.html

Applications are due no later than November 1st in the fall semester or the first Thursday after Spring Break in the spring term. Students should submit their KEY Program materials to Lattimore 312. Letters of recommendation are due the same day as the application and should be sent directly to Lattimore 312.

A list of courses that has been developed with entrepreneurship in mind can be found at www.rochester.edu/entrepreneurship/courses.

Students should also consult the faculty with whom they want to study, and/or the appropriate departmental administrators to be sure that the courses they want to take will be offered, and that they are adequately prepared for the courses they intend to take. Each applicant needs to arrange for two full-time faculty members to send letters of recommendation to the KEY Review Board on his or her behalf.

TEAM

The Master of Science in **Technical Entrepreneurship And Management**, or TEAM degree program at the University of Rochester offers students the opportunity to immerse themselves in a technical cluster of their choice while receiving a strong foundation in entrepreneurial management. Through a fast-paced curriculum at the University's Edmund A. Hajim School of Engineering and Applied Sciences and the William E. Simon Graduate School of Business, students can complete the program in as little as one academic year.

TEAM graduates are equipped with detailed technical knowledge in their field as well as business-savvy. They have the tools to innovate, lead, and strategically manage in an industry that increasingly rewards interdisciplinary expertise. Seventy-five percent of the Class of 2010 received multiple job offers before graduation.

For additional information: www.rochester.edu/team/

BIOMEDICAL ENGINEERING COURSES AND PRE-REQUISITES

BME 101/EAS 101 Introduction to Biomedical Engineering

This course provides an introductory overview of the multi-disciplinary field of biomedical engineering. Application of elementary engineering principles to the analysis of physiological systems. Topics include biomechanics, cell and tissue engineering, biosignals and bioinstrumentation, medical imaging, neuroengineering and medical optics. Includes instruction on the use of computers in engineering. This course is open to all freshmen (or sophomores with permission of instructor) interested in an introduction to the field of biomedical engineering. (Cross-listed as EAS 101) Semester Taught: Fall - CREDITS: 4

BME 201 Fundamentals of Biomechanics

BME 201 teaches elementary mechanical equilibrium and motion with extended applications to biology. Lectures present a traditional analysis of idealized particles and rigid bodies. Topics include force and moment balances, frames, trusses and pulleys, systems with friction, mass centers, area moments, and the linear and rotational kinetics and kinematics of rigid bodies. Weekly exercises apply fundamental principles to non-biological problems in two and three dimensions. Weekly problems extend the application to biological problems ranging from human motion to the mechanics of cells. In an end-of-term project, students analyze human motion using the MATLAB programming language. This is a required course for BME majors typically taken in the sophomore year. Prerequisites: MTH 161 and 162, BME 101, PHY 121. Concurrent with BME 201. Semester Taught: Fall - CREDITS 4

BME 201P MATLAB for Biomechanics

Fundamentals of computer programming in MATLAB. Emphasis on programming basics, such as syntax, loop structures, logic, input/output, and graphics. Semester Taught: Fall - CREDITS: 1

BME 210 Biosystems & Circuits

Introduction to electrical circuit theory. Examples will include bioelectric systems and signals and models of biological systems. Semester Taught: Spring - CREDITS: 4

BME212/412 Viscoelasticity in Biological Tissues

Viscoelastic materials have the capacity to both store and dissipate energy. As a result, properly describing their mechanical behavior lies outside the scope of both solid mechanics and fluid mechanics. This course will develop constitutive relations and strategies for solving boundary value problems in linear viscoelastic materials. In addition, the closely-related biphasic theory for fluid-filled porous solids will be introduced. An emphasis will be placed on applications to cartilage, tendon, ligament, muscle, blood vessels, and other biological tissues. Advanced topics including non-linear viscoelasticity, composite viscoelasticity and physical mechanisms of viscoelasticity will be surveyed. Prerequisites: ME226, BME201, and 201P. Semester Taught: Spring – CREDITS: 4

BME 218/418 Introduction to Neuroengineering

This course introduces many aspects of neuroengineering research, with an emphasis on biologically plausible models of neurons, circuits, and systems. The course begins with a brief review of passive membrane properties and Hodgkin-Huxley channel dynamics, and extends to advanced topics including neural circuits, control systems, and biologically plausible neural models of behavior. There is an emphasis on theory, modeling, and simulation of single neurons, neural networks, and systems. Prerequisites: BME 260, strong computing skills recommended or permission of instructor. Semester Taught: Fall – CREDITS: 4

BME 221 Biomedical Computation & Statistics

Numerical and statistical methods of scientific computing and their applications to modeling of biomedical systems and interpretation of experimental data, using the MATLAB programming language. Prerequisites: BME 201 and 201P, or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME 228/448 Physiological Control Systems

This course focuses on the application of control theory to physiological systems. Lectures present modern control theory in the context of physiological systems that utilize feedback mechanisms. Prerequisites: juniors with MTH164, MTH163/165, BME201L and ECE241 or equivalent. Seniors need BME230 in place of ECE241. Semester Taught: Fall – CREDITS: 4

BME 230 Biomedical Signals, Systems, and Imaging

Introduction to continuous and discrete time signals and linear time invariant systems, with applications to BME including imaging. Topics include convolution. Laplace and Z transforms, stability of systems, the Fourier series and transform, noise and filtering, and fundamental concepts in image processing and enhancement. Prerequisites: BME 210 or equivalent, MTH163/165 Semester Taught: Fall - CREDITS: 4

BME 245 Biomaterials

This course provides a background in biomaterials. It covers basic material properties, specifics on ceramics, polymers and metals used in the body, biological responses to implanted materials, and special topics related to biomaterials including tissue engineering, drug delivery, and sensors. At the end of the course, students are expected to articulate design criteria for engineered biomaterials with respect to chemistry, mechanics, lifetime, tissue integration, and FDA approval and be able to recommend optimum designs for different applications. The class is divided into three general sections: 1) Basic material structures of common biomaterials: Metals, Ceramics, and Polymers and how these structures are tested, 2) Cell and Tissue Interactions with Biomaterials (inflammation, wound healing, immune response, etc.), 3) FDA approval and applications of biomaterials (including drug delivery, tissue engineering, sensors). Semester Taught: Spring – CREDITS: 4

BME 251/451 Biomedical Ultrasound

The physical basis for the use of high-frequency sound in medicine (diagnosis, therapy, and surgery) and biology. Topics include acoustic properties of tissues, sound propagation (both linear and nonlinear) in tissues, interactions of ultrasound with gas bodies (acoustic cavitation and contrast agents), thermal and non-thermal biological effects of ultrasound, ultrasonography, dosimetry, hyperthermia and lithotripsy. Prerequisites: Math 163, Math 164, Physics 122 or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME253/453 Ultrasound Imaging

Introduction to the principles and implementation of diagnostic ultrasound imaging. Topics include linear wave propagation and reflection, fields from pistons and arrays, beamforming, B-mode image formation, Doppler, and elastography. Prerequisites: BME 451 or permission of instructor. Semester Taught: Fall – CREDITS: 4

BME 255/455 Translational Biomedical Optics

This course will focus on the macroscopic biomedical optics techniques (e.g., diffuse optical spectroscopy and tomography, photoacoustic tomography) with high potential for clinical translation. Students will learn the aspects of instrumentation design, analytic and numerical approaches for optical data analysis, and validation of new technologies in the clinical setting. Semester Taught: Fall – CREDITS: 4

BME/BIO 258 Human Anatomy

Human Anatomy is the detailed study of the human organism at the cellular, tissue and organ systems levels. The relationship between structure and function is covered with emphasis on structural relationships. The course includes both lectures and laboratory sessions, and provides a basis for further professional and clinical experience. (Students cannot take both BME/BIO258 and BIO 203). Semester Taught: Spring - CREDITS: 4

BME 259 Transport Phenomena in Biological Systems

This course will provide an overview of transport phenomena in biological systems that are critical to the function of all living organisms. The fundamental laws and equations of transport phenomena will be applied to topics including cellular, cardiovascular, respiratory, liver and kidney transport, blood flow and rheology, and circulation in tissues and arteries. Homework assignments, in-class quizzes, final exam and a technical paper or presentation. Semester Taught: Fall – CREDITS: 4

BME 260 Quantitative Physiology

A quantitative, model-oriented approach to physiological systems is presented. Topics include: muscle and nerve tissue, the cardiovascular system, the respiratory system, the renal system, and a variety of neural systems. Prerequisite: ECE 113 or BME 210 or permission of instructor. Semester Taught: Fall – CREDITS: 4

BME 262/462 Cell & Tissue Engineering

This course teaches the principles of modern cell and tissue engineering with a focus on understanding the fundamental interactions between cells and their environment and an emphasis on the concepts relevant to the practice of cell and tissue engineering. The course covers the following modules: Prerequisites: BME 260, CHE 225, CHE 243, CHE 244 or permission of instructor. Elements of Embryonic Development and Tissue Healing in Tissue Engineering; Cell and Molecular Biology Technologies (cell sourcing, cell culture, growth, differentiation, gene transcription and translation); Stem Cells; the ECM (types of tissues and extracellular matrix constituents); Biomaterials (natural polymers, degradable synthetic polymers, degradable bioceramics, scaffold design and fabrication); Biocompatibility and Basic Immunology; Controlled Drug Release Strategies; Cell Signaling; Strategies to Improve Cell Nutrition, Diffusion & Mass Transport in Engineered Tissues; Bioreactor Technologies; Gene Therapy; and Tissue Mechanics and Mechanobiology. Prerequisites: BME 260, CHE 225, CHE 243, CHE 244, or permission of instructor. In a term project, graduate students must identify a technological need and present orally and in writing a proposal to meet the need. Semester Taught: Spring - CREDITS: 4

BME 267/467 Models and Simulations of Biomedical Systems

Introduction to analytical modeling and computational simulations of systems. Examples include cardiovascular, respiratory, muscle, neural and population models. Prerequisites: BME 221 and BME 230
Semester Taught: Fall - CREDITS: 4

BME 270/470 Biomedical Microscopy

This course covers the principles and practice of light microscopy as applied to biological and medical questions. Topics include basic light microscopy, epifluorescence, confocal and multiphoton laser-scanning microscopy, and selected methods such as CARS, FRET, FRAP, FCS, etc. Prerequisites: OPT 241, OPT 261, BME201P, MTH 163/165, MTH 164 or permission of instructor. Fall 2013, then Spring semester beginning in 2014 – CREDITS: 4

BME274/474 Biomedical Sensors, Circuits & Interfacing

Course will cover circuits and sensors used to measure physiological systems at an advanced level. Both signal conditioning and sensor characteristics will be addressed. Topics will include measurement of strain, pressure, flow, temperature, biopotentials, and physical circuit construction. The co requisite Laboratory will focus on the practical implementation of electronic devices for biomedical measurements. Prerequisites: BME210, ECE113 or equivalent, or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME/OPT 276 Biomedical Optics

Major topics are biomedical spectroscopy (absorption, fluorescence, Raman, elastic scattering); propagation of photons in highly scattering media (such as tissue); techniques for high-resolution imaging in biological media: confocal imaging, multi-photon imaging, and optical coherence tomography.
Semester Taught: Fall alternate years – CREDITS: 4

BME 283/483 Biosolid Mechanics

Application of engineering mechanics to biological tissues including bone, soft tissue, cell membranes, and muscle. Realistic modeling of biological structures, including musculoskeletal joints and tissues. Investigations of the responses of biological tissues to mechanical factors. Experimental methods and material models. Same as ME 483 and BPH 483. Prerequisites: ME 226, BME 201, and 201P.
Semester Taught: Fall – CREDITS: 4

BME 295 BME Design Seminar

Guided sessions for project development will be held, using brainstorming and other techniques, and then students will develop proposals and specifications for their projects. Presentations will be given describing all the proposed projects and students will be given an opportunity to turn in resumes to apply to work on projects of their choice. Students who wrote the proposals will select teams for the applicants, and final project execution will be carried out in the spring semester. Prerequisites: math, science, and engineering courses appropriate for fourth-year students in BME. Semester Taught: Fall - CREDITS: 2

BME 296 BME Senior Design Project

Senior capstone design course in the Biomedical Engineering Program. Students work in teams to design, build, and test a medical device or instrument for a faculty, community or industrial sponsor. Accompanying lectures and discussions introduce issues related to ethics, economics, project management, regulation, safety, and reliability. Prerequisites: math, science, and engineering courses appropriate for fourth-year students in BME, BME 295, BME 260, or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME 404 Computational Methods Applied to Biology Systems

Computational methods to solve analytically intractable mathematical problems in biological research. Using MATLAB as a programming language; Numerical methods for linear algebra, ODE and PDE; Case studies such as biodynamics of human locomotion, ion channel kinetics, ionic diffusion in cells and finite element analysis of cells/tissues. Semester Taught: Spring – CREDITS: 4

BME 442 Microbiomechanics

From single molecule motors transporting materials within cells to contracting muscle fibers, molecular engines come in a range of sizes and produce some of the most fascinating phenomena in biology. This course teaches the modern theories behind molecular engines, presuming only an elementary background in cell biology and mechanics. Prerequisites: permission of instructor. Semester Taught: Second 1/2 of the Spring semester – CREDITS: 2

BME 445 Biomaterials Science and Engineering

This course focuses on contemporary issues affecting the design, fabrication, characterization and performance of current biomaterials used in medical components, surgical implants, prosthetics and diagnostic devices. Course content assumes a basic background in materials science, physiology, cell biology, and would benefit from an introduction to biomaterials or bioengineering. The lectures intend to promote critical review of the “state-of-the-art” biomaterial technologies by graduate students/advanced undergraduate students to identify the significant knowledge gaps required to overcome challenges and further biomaterials development. Primary topics to be discussed constitute several of the independent parameters that may influence design of novel multi-functional biomaterials in biomedical systems. A research-oriented problem-solving perspective is featured. Prerequisite: Graduate student or senior undergraduate by permission of instructor. Semester Taught: Fall CREDITS: 2 (Fall 2013)

BME/OPT 448 Principles of Eye Design

This course explores the design of the human eye, revealing the optical and neural factors that limit color and spatial vision. The design of eyes (such as those of predatory birds and the compound eyes of insects) that evolved to operate in environments different from that of the human eye are examined. The course begins with a treatment of the information losses associated with the eye's optics, the photoreceptor mosaic, and the ganglion cell array that transmits visual information to the brain. The course ends with a discussion of image processing by the visual cortex of the brain. Cross-listed: OPT 448/CVS492 – Semester Taught: Spring – CREDITS: 4

BME 452 Medical Imaging - Theory & Implementation

Physics and implementation of X-ray, ultrasonic, and MR imaging systems. Special attention is given to the Fourier transform relations and reconstruction algorithms of X-ray and ultrasonic-computed tomography, and MRI. Prerequisites: ECE 242 Cross-listed: ECE 452. Semester Taught: Fall – CREDITS: 4

BME 453 Advanced Biomedical Ultrasound

This course investigates the imaging techniques applied in state-of-the-art ultrasound imaging and their theoretical bases. Topics include linear acoustic systems, spatial impulse responses, the k-space formulation, methods of acoustic field calculation, dynamic focusing and apodization, scattering, the statistics of acoustic speckle, speckle correlation, compounding techniques, phase aberration correction, velocity estimation, and flow imaging. A strong emphasis is placed on readings of original sources and student assignments and projects based on realistic acoustic simulations. Prerequisites:

BME 230/ECE 241, BME251/451 or equivalent or permission of instructor. Semester Taught: Fall – CREDITS: 4