

UNDERGRADUATE  
BIOMEDICAL ENGINEERING  
CURRICULUM GUIDE  
SEPTEMBER 2016



UNIVERSITY of  
**ROCHESTER**  
BIOMEDICAL ENGINEERING

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## **BME PRIMARY FACULTY**

### *Chair of the Department*

Diane Dalecki, Ph.D. (Rochester) *Distinguished 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*

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) *Associate 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) *Marylou Ingram Professor of Biomedical Engineering and of Neuroscience, and Electrical & Computer Engineering*

*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.*

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

*Research Area – The process of commercialization medical technologies from identifying unmet clinical needs to the design, fabrication, marketing, regulatory and intellectual property aspects of medical devices*

Catherine Kuo, Ph.D. (Michigan) *Associate Professor of Biomedical Engineering and Center for Musculoskeletal Research*

*Research Area – Tissue engineering, mechanobiology, stem cells, biomaterials, scaffolds, bioreactors, animal microsurgery, embryonic development, wound healing, regenerative medicine*

Edmund Lalor, Ph.D. (University College Dublin) *Associate Professor of Biomedical Engineering and of Neuroscience*

*Research Area - Sensory systems neuroscience, computational neuroscience, attention, neural processing of speech, multisensory integration, brain-computer interfacing.*

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 - Orthopaedic biomechanics, cartilage mechanics, medical image-based finite element modeling, knee biomechanics*

Anne E. Luebke, Ph.D. (Johns Hopkins) *Associate Professor of Biomedical Engineering and of Neuroscience*  
*Research Area - Gene transfer to the cochlear, stem cell transfection, molecular biology of auditory efferent system receptors*

Ross Maddox, Ph.D. (Boston) *Assistant Professor of Biomedical Engineering and of Neuroscience*  
*Research Area - Auditory neuroscience; Audio-visual integration; Selective attention; Development of electroencephalography paradigms for research and diagnosis.*

Stephen McAleavey, Ph.D. (Rochester) *Associate Professor of Biomedical Engineering and of Electrical and Computer 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. (Virginia Tech) *Associate Professor of Mechanical Engineering and of 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 Neuroscience*  
*Research Area – Embedded systems for healthcare, medical device innovation, assistive devices, neuroengineering*

Richard E. Waugh, Ph.D. (Duke) *Professor of Biomedical Engineering, of Pharmacology & 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*

## **JOINT APPOINTMENTS WITH BIOMEDICAL ENGINEERING**

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

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

Robert Clark, Ph.D. (Virginia Tech) *Professor of Mechanical Engineering and of Biomedical Engineering;*  
*University of Rochester Provost*

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

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

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

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

Vikram Dogra, Ph.D. (University of Madras, India) *Professor of Imaging Sciences and of Biomedical Engineering*

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

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

Angela Glading, Ph.D. (Pittsburgh) *Associate Professor of Pharmacology & Physiology and of Biomedical Engineering*

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

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

Thomas Howard, Ph.D. (Carnegie Mellon) *Assistant Professor of Electrical and Computer Engineering and of Biomedical Engineering*

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

William Merigan, Ph.D. (Maryland) *Professor of Ophthalmology and Biomedical Engineering and Center for Visual Science*

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 Imaging Sciences, of Electrical and Computer Engineering and of Biomedical Engineering*

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

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

Tatiana Pasternak, Ph.D., (University of Copenhagen ) *Professor of Neuroscience, of Brain & Cognitive Sciences, and of Center for Visual Science*

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. (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 & Physiology and of Biomedical Engineering*

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

Marc Schieber, M.D. (Washington Univ. Med Center) *Professor of Neurology, and of Neuroscience, and of Center for Visual Science*

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 & Cognitive Sciences*

Axel Wismüller, M.D., Ph.D., (Technical University, Munich, Germany), *Professor of Imaging Sciences and of Biomedical Engineering*

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

Geunyoung Yoon, Ph.D. (Osaka) *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 Imaging Sciences, of Biomedical Engineering and of Physics*

Michael Zuscik, Ph.D. (Rochester) *Associate Professor of Orthopaedics, Center for Musculoskeletal Research*

### **AFFILIATED FACULTY**

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

Victor Derefinko, M.S. (Virginia), *Adjunct Professor of Electrical & Computer Engineering*

Martha Gdowski, Ph.D. (Pennsylvania), *Associate Professor of Neuroscience*

Scott Kennedy, Ph.D. (Rochester) *Research Assistant Professor of Biochemistry & Biophysics*

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*

Karl Schwarz, M.S. (Rochester) *Professor of Medicine and of Anesthesiology*

Peter G. Shrager, Ph.D. (California, Berkeley) *Professor of Neuroscience*

### **ADJUNCT FACULTY**

Joan Adamo, Ph.D. (Cornell) *Adjunct Assistant Professor, Associate Director, Regulatory Support Services, University of Rochester Clinical Translational Science Institute*

Jason Condon, M.S. (U of Pennsylvania) *Adjunct Assistant Professor, Project Manager, CMC at Vaccinex, Inc.*

Kevin Davis, Ph.D. (Boston) *Adjunct Associate Professor, Lecturer, Brain & Cognitive Sciences*

Nipa Mody, Ph.D. (Rochester) *Adjunct Assistant Professor, Senior Engineer at Ortho Clinical Diagnostics*

Owen Papuga, Ph.D. (Rochester) *Adjunct Assistant Professor, Assistant Professor New York Chiropractic College*

## 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 has been accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org> 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 & Biosystems, Cell & 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 131 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, 164, 165

*(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 or PHY 121P, PHY 122 or PHY 122P

*(PHY113 may be a required substitute for PHY121 for those students in the MTH 141-3 series)*

One Biology course - BIO 110\*\*

\* Students with a strong chemistry background (AP >4) may choose to take the CHM 17x series, Freshman Organic Chemistry. This sequence is not a direct replacement for 131 and 132, however, since it does not cover all chemistry material necessary for the major. Therefore, students may take any of the following combinations:

CHM131 (or AP>=4) and CHM132

CHM171 and CHM132

CHM171, CHM172 and CHM132

CHM171, CHM172 and CHM252

\*\* Most BME students take BIO 110 during the sophomore year. However, students with AP credit for BIO *and* room in their schedules freshman year (due to additional AP credit in Chemistry or Math) may choose to take BIO 112 during their freshman year. Students with AP credit for Biology will receive 4 credits of elective biology, but are still required to take BIO 110 or 112.

## **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 course descriptions provided.)*

BME 101/EAS101 - Introduction to Biomedical Engineering (with lab)

BME 201 - Fundamentals of Biomechanics

BME 201P - MATLAB for Biomedical Engineering (1 credit)

BME 210 - Biosystems and Circuits (with lab)

BME 221 - Biomedical Computation & Statistics ( with 099 lab)

BME 230 - Biomedical Signals, Systems & Imaging (with lab)

BME 245 – Biomaterials (with 099 lab)

BME 260 - Quantitative Physiology (with lab)

BME 295 - BME Design Seminar (2 credits)

BME 296 - BME Senior Design

## **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>.

## **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

### **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.

Some examples for Basic Science Elective sequences are provided below. Students are advised to check pre-requisites for courses.

#### *Example 1:*

BME 258 - Human Anatomy (4 credits, spring - includes laboratory component)  
BIO 204 – Mammalian Physiology (4 credits, spring) with BIO 204P Lab (1 credit, fall)  
PHY 123 – Waves & Modern Physics (4 credits, spring - includes laboratory component)

*Example 2: (This sequence is **required** for students in the Cell & Tissue Engineering Concentration – students may choose one of the two labs or may take both)*

CHM 203 – Organic Chemistry I (4 credits, fall) with CHM 207 – Organic Chem. Lab I (1 credit, fall)  
BIO 250 – Biochemistry (4 credits, spring)  
BIO 210 – Molecular Cell Biology (4 credits, fall, no laboratory component)

#### *Example 3:*

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)

Other examples of approved BSEs are:

AST142 Elementary Astrophysics	BIO250 Introduction to Biochemistry
AST231 Gravitation & General Relativity	BIO210 Molecular Cell Biology
BIO190 Genetics & the Human Genome	CHM203 Organic Chemistry
BIO198 Principles of Genetics	NSC201 Basic Neurobiology
BIO 217 Principles of Human Anatomy	NSC243 Neurochemical Foundations of Behavior
BIO202 Molecular Biology	NSC245 Sensory & Motor Neuroscience
BIO204 Mammalian Physiology	NSC249 Developmental Neurobiology
BIO205 Evolution	MBI 220 Intro to Microbiology
BIO206 Eukaryotic Genomes	PHY 123 Modern Physics

These courses do not fit the description of a life science BSE course, but WILL be accepted as such:

BCS110 Neural Foundations of Behavior  
BCS221 Auditory Perception  
BCS223/OPT 248 Vision and the Eye  
BME258 Human Anatomy  
CHM262 Biological Chemistry

These courses Will NOT be accepted as a Basic Science Electives:

BIO111 Principles of Biology II  
BIO112 Perspectives in Biology  
BIO113 Perspectives in Biology II  
BIO214 Biostatistics  
BIO253 Computational Biology  
CHM137 Chemistry Principles for Engineers  
PHY252, PHY257/457 Biomedical Ultrasound

**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 either 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.

\*\*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.

**Communicating Your Professional Identity (2 credit hours)**

All students must complete WRT 273, an interactive course designed to teach “real life communication skills and strategies that help students present their best professional selves”. Students will explore and articulate their internship, career and graduate school goals for distinct audiences and purposes as they develop a professional communication portfolio of materials such as resumes, cover letters, statements of purpose, electronic communications, technical project abstracts, online profiles (i.e., LinkedIn), and oral presentations. Most students will complete this course in the spring of the sophomore year, but it may also be taken during the fall of the junior year.

**Free Electives (8 credit hours)**

Any courses taken at the University of Rochester, AP courses, study abroad or transfer courses may be used for elective credits.

# **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)  
PHY121 or 121P-Mechanics (lab); **OR** PHY 113 if required  
H/SS **OR** Primary Writing

## **2nd Year**

### **Fall**

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

### **Spring**

MTH 164-Multidimensional Calculus  
\*\*\*1<sup>st</sup> concentration course or Basic Science Elective  
BME 210-Biosystems & Circuits (lab) (*Core*)  
H/SS  
\*\*WRT 273-Communicating Professional Identity – 2 cr.

NOTES:\*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. MTH170 series can be used to fulfill the Math requirements

\*\* WRT 273 may be taken in the fall of the junior year.

\*\*\* **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 (H/SS), and Elective courses can be taken in any semester.**

# **THIRD & FOURTH YEARS**

## **CELL & TISSUE ENGINEERING**

## **3rd Year**

### **Fall**

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

### **Spring**

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

## **4th Year**

### **Fall**

BME 260 - Quantitative Physiology (*Core*)  
BME 295 - Design Seminar (2 cr.) (*Core*)  
CHE 225-Thermodynamics  
BME 411 – Found of Cell & Molecular Biology  
**OR** BIO 202 – Molecular Biology  
**(OR BIO210 in Spring semester)**

### **Spring**

BME 296 - Senior Design (*Core*)  
Upper Level BME (BME262)  
Elective  
BIO 210 - Molecular Cell Biology (if not taken in fall)  
H/SS

# BIOSIGNALS & BIOSYSTEMS

## 3rd Year

### Fall

BME 230 – Signals, Systems, & Imaging (*Core*)  
ECE230 – Electromagnetic Waves  
Basic Science Elective  
ECE 221-Electronic Devices & Circuits **OR**  
BME 228- Physiological Control Systems

### Spring

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

## 4th Year

### Fall

BME 260 - Quantitative Physiology (*Core*)  
BME 295 - Design Seminar (2 cr.) (*Core*)  
ECE246 - Digital Signal Processing  
Upper Level BME (BME 218 or ECE 452)  
**OR** Elective

### Spring

BME 296 - Senior Design (*Core*)  
H/SS  
Elective  
Elective **OR** Upper Level BME (BME 251)

# BIOMECHANICS

## 3rd Year

### Fall

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

### Spring

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

## 4th Year

### Fall

BME 260 - Quantitative Physiology(*Core*)  
BME 295 - Design Seminar (2 cr.) (*Core*)  
ME 225 – Introduction to Fluid Dynamics  
Upper Level BME (BME 283) **OR** Elective

### Spring

BME 296 - Senior Design (*Core*)  
Elective **OR** Upper Level BME (BME 212)  
H/SS  
Basic Science Elective

# MEDICAL OPTICS

## 3rd Year

### Fall

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

### Spring

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

## 4th Year

### Fall

BME 260 - Quantitative Physiology (*Core*)  
BME 295 - Design Seminar (2 cr.) (*Core*)  
Upper Level BME (BME 255) **OR** Elective  
H/SS

### Spring

BME 296 - Senior Design (*Core*)  
Elective **OR** Upper Level BME (OPT 276)  
Elective  
Basic Science 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 an online 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 the two remaining 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 2.0 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 Curriculum and Career Planning Forms, and the online Major Declaration form

A BME Career Planning form must accompany the major declaration forms. 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 materials and then discuss the alternatives fully with his or her faculty adviser or with other faculty. The university requirement that a student should be free of academic probation also applies. The Curriculum Planning Form, approved and signed by the student's faculty adviser, must also be completed for a BME Major Declaration. An online Declaration of Major form must be filled out and will be reviewed by the BME Undergraduate Committee Chair. When approved, the online form is automatically 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 this situation may fill out the BME Major Declaration paperwork and will be considered when they have completed all necessary coursework for admission to the major. The application must present a realistic plan, approved by the student's adviser, for completion of all BME program admission requirements.

Only the Administrative Committee of the College of Arts, Sciences and Engineering 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 131 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 adviser and to obtain approval for course equivalency **before** registering for a course at another institution.

## 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 the Gwen M. Greene Career and Internship Center in Dewey Hall, 4<sup>th</sup> floor, [www.rochester.edu/careercenter/](http://www.rochester.edu/careercenter/)

## STUDY ABROAD

The Hajim School of Engineering and Applied Sciences highly recommends engineering students study abroad and aims to have ~25% of all UR engineering students participate. Study Abroad experiences are achievable through early planning. Our students have traveled to China, Ireland, New Zealand, Australia, England, Spain, South Africa and other countries. If you are considering spending a semester, or a summer in another country, please check out the UR Education Abroad 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 Education Abroad as you plan. The Center is located in Dewey 2-161 206, and is there to help you, to share your excitement, and to assist you in making it all work. Additional information at:

<https://www.rochester.edu/College/abroad/>

Please see Undergraduate Coordinator Taimi Marple for early guidance. Biomedical Engineering faculty dedicated to Study Abroad are Professors Anne Luebke ([anne\\_luebke@urmc.rochester.edu](mailto:anne_luebke@urmc.rochester.edu)) and Scott Seidman ([scott\\_seidman@urmc.rochester.edu](mailto:scott_seidman@urmc.rochester.edu)). Students are encouraged to share their plans and interests with Professors Luebke or Seidman before departure.

## PRE-MEDICAL PROGRAM

BME students interested in a pre-med program or other health professions, such as nursing, physical therapy or veterinary medicine are urged to obtain related materials from the Health Professions Advisers in the Gwen M. Greene Career and Internship Center in Dewey Hall, 4<sup>th</sup> floor. It is essential that such students begin program planning very early and involve both their BME adviser and the Health Professions Adviser. Additional information at: <http://www.rochester.edu/college/health/>.

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, one semester of Biochemistry, and some exposure to Psychology. Note that the requirements and expectations for the MCAT exam may change over time and vary between programs. Therefore, it is important to consult the Health Professions office periodically and check individual program requirements.

## 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 nine 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 tuition award of up to 50 percent 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/professional/gear/>

## 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 master's degree in one year. (Note that a thesis master's degree 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.

<http://www.bme.rochester.edu/graduate/ms.html>

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

[www.rochester.edu/GradBulletin](http://www.rochester.edu/GradBulletin)

## MEDICAL TECHNOLOGY & INNOVATION

Another MS option is the Center for [Medical Technology & Innovation \(CMTI-MS\)](http://www.cmti.rochester.edu/) option of our coursework MS degree in Biomedical Engineering. 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.

<http://cmti.rochester.edu/>

## 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/>

## TEAM

The Master of Science in **T**echnical **E**ntrepreneurship **A**nd **M**anagement, 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. The overall placement rate for TEAM graduates is 90% within six months of graduation. Applications are due by February 1<sup>st</sup>.

For additional information: [www.rochester.edu/team/](http://www.rochester.edu/team/)

### **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 Center for Advising Services counter outside Lattimore 312.

Additional information at: <https://www.rochester.edu/college/ccas/AdviserHandbook/KEY.html>

Applications are due no later than November 1<sup>st</sup> 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](http://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.

## 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 Taimi Marple for information on how to submit an online 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, BME 257 Essential Molecular Biology, BME 258 Human Anatomy, 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 advisers 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. BME 257 Essential Molecular Biology and BME 258 Human Anatomy can NOT be used for this requirement.

*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 210 Biosystems and Circuits
- 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 253 Ultrasound Imaging
- BME 255 Translational Biomedical Optics
- BME 259 Transport Phenomena in Biological Systems
- BME 260 Quantitative Physiology
- BME 262 Cell and Tissue Engineering
- BME 266 Bioprocess Engineering
- BME 267 Models and Simulations of Biomedical Systems
- BME 270 Biomedical Microscopy
- BME 283 Biosolid Mechanics
- BME 391 Independent Study

# 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 201P. Semester Taught: Fall - CREDITS 4

## **BME 201P MATLAB for Biomedical Engineering**

Fundamentals of computer programming in MATLAB. Emphasis on programming basics, such as syntax, loop structures, logic, input/output, and graphics. Co-requisite: BME201. 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. Prerequisites: PHY 122, MTH 162, BME 201P, MTH 165 may be a corequisite. 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: ME225 or CHE243, and ME226. 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, MTH 165 and BME 230 or ECE 241 (can be concurrent).

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, MTH 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). Prerequisites: CHM132, PHY122, MTH162, BME 201 and BIO110 or permission of instructor.

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: MTH 164, MTH 165, PHY 122 or permission of instructor.

Semester Taught: Spring – CREDITS: 4

### **BME253/453 Ultrasound Imaging**

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, flow imaging, and elastography. A strong emphasis is placed on readings of original sources and student assignments and projects based on realistic acoustic simulations. Prerequisites: BME 230 or ECE 241 or equivalent. 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 technology in the clinical setting. Pre-requisites: BME221, OPT241, OPT261. Semester Taught: Fall – CREDITS: 4

### **BME 257 Essential Molecular Biology**

Cell biology and molecular biology are the core of modern biomedical science, whether applied to systems or to cells. The goal of this course is to provide students with a strong foundation of molecular biology and practical knowledge to support future research efforts, and to enable students without extensive backgrounds in biological sciences grasp fundamentals of molecular biological principles. Prerequisites: BIO 110 or permission of instructor. (BME students can not take BIO202 and BME257 to fulfill major requirements.) Semester Taught: Summer – CREDITS: 4

### **BME 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.

Prerequisites: BIO 110 or equivalent. (BME students cannot take both BME 258 and BIO 217 to fulfill major requirements). 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. Prerequisites: PHY 121, MTH 164, MTH 165 required, CHE243 *desirable*.

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: 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 *or* ME 123, CHE 243 *or* ME225, CHE 244, BIO210 (or BIO202 or BME411), BIO 250, CHM203 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 266/466 Bioprocess Engineering**

This course will explore the bioprocesses involved in producing a biopharmaceutical product (therapeutic proteins, cell therapy products, and vaccines). The course will take a stepwise journey through a typical production process from the perspective of a Bioprocess Engineer, starting with cell culture and moving downstream through purification and final fill. Engineering concepts involved in bioreactor design and control, cell removal/recovery operations, and protein purification will be examined. The course will also provide an introduction to the analytical methods used to test biopharmaceutical products for critical quality attributes. The role of the regulatory agencies, like the US Food and Drug Administration, and the regulations that govern the industry will be introduced throughout the course in the context of the bioprocess to which they relate. Graduate students will need to complete a semester-end project in order to receive graduate credit for the course. Prerequisites: BIO 110, CHM 132, CHE243 *or* ME225, CHE244. Semester Taught: Spring – CREDITS: 4

### **BME 270 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: MTH161, MTH162, MTH 164, MTH 165, PHY122, OPT 241, OPT 261 or permission of the instructor. Semester Taught: Spring – 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 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 *or* ME 120. 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. Prerequisites: Fundamental linear algebra, ordinary differential equations, some experience of MATLAB. Semester Taught: Fall – CREDITS: 4

**BME 411 Cellular & Molecular Biology Foundations**

Molecular biology, biochemistry, and genetics that are required to understand the biomedical and broader biological issues that affect our lives. Note: You must register for a recitation when registering for the main section. Prerequisites: BIO 110. Semester Taught: Fall – 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: Spring semester – CREDITS: 4

**BME/ECE 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