PhD in Biomedical Engineering

Admission Requirements

The application procedures and admission requirements to the PhD program follow AUB's General University Academic Information as documented in the Graduate Catalogue. To be considered for admission, applicants must hold a bachelor's or master's degree in a relevant field of study from AUB or its equivalent, or from a recognized institution of higher learning.

Acceptance into the PhD program is determined by academic performance as well as an assessment of readiness, potential and ability to develop into independent researchers as judged by interviews by faculty members, a written statement, letters of recommendation, GRE scores, and other means of assessment such as publications and industrial experience.

Accepted students are eligible to receive scholarships that fully cover their tuition fees and provide a monthly stipend.

Degree Requirements

General requirements for master's degree holders: Based on AUB's guidelines, a minimum of 48 credit hours beyond those required for the master's degree, of which a minimum of 18 credit hours must be in graduate level course work and a minimum of 24 credit hours of thesis work, must be taken. Requirements also allow a maximum of 3 credit hours out of the 18 credits of coursework as tutorial course and include a 0-credit comprehensive examination preparation course and a 0-credit thesis proposal preparation course.

General requirements for bachelor's degree holders: Based on AUB's guidelines, a minimum of 78 credit hours beyond those required for the bachelor's degree, of which a minimum of 36 credit hours must be in graduate level coursework and a minimum of 30 credit hours of thesis work, must be taken. Requirements also allow a maximum of 6 credit hours out of the 36 credits of coursework as tutorial courses and include a 0-credit comprehensive examination preparation course and a 0-credit thesis proposal preparation course.

To earn a PhD degree in Biomedical Engineering, the student must complete the following requirements:

- Satisfy the course and research credit requirements
- Satisfy the residence requirement and all other pertinent AUB regulations
- Have at least one international refereed journal article based on the PhD thesis
- Have at least one refereed conference paper based on the PhD thesis
- Have a cumulative average of 85 (3.7) or above
- Pass the comprehensive and oral qualifying examinations
- Successfully defend the PhD thesis

The following are the graduate level course requirements for students admitted with a bachelor's degree. The total number of credits is at least 36 credits divided among core, restricted elective and free elective courses. Students admitted with a master's degree can waive as many courses as possible without going below the minimum required 18 credits of coursework.

Core graduate courses: 21 credits of core courses from biomedical sciences and engineering.

Required core courses (21 cr.)		Credits
BIOC 321	Nucleic Acids and Basic Genetics	1
BIOC 322	Protein Biochemistry	1
BIOM 385	Research Ethics	1
BMEN 600	Biomedical Engineering Applications	3
BMEN 601	Computational Modeling of Physiological Systems	3
BMEN 671	PhD Lab Rotation[1]	1+1
BMEN 672	Hospital Lab Rotation	0
BMEN 673L	Biomedical Engineering Lab	1
BMEN 675	Approved Experience	0
EPHD 310	Basic Biostatistics[2]	3
HUMR 310 (A, B, or C)	Biomedical Research Techniques	1
HUMR 314	Research Seminar	1
PHYL 346	Human Physiology	4

Restricted elective graduate courses: 9 credits restricted elective courses customized per focus area.[3]

Restricted elective courses (9 cr.)[3]		Credits	Systems	Cyber-netics	Cardio-vascular
BIOC 325	Receptors and Signal Transduction	2		R	
BIOC 326A	Bioinformatics Tools and Applications in Genomics	1		R	
BMEN 603	Tissue Engineering	3	X		X
BMEN 604	Engineering of Drug Delivery Systems	3	X		X
BMEN 605	Biomedical Imaging	3		X	X
BMEN 606	Nanobiosensors	3	X	X	
BMEN 607	Biomechanics	3	X		
BMEN 608	Biomaterials and Medical Devices	3	X		X
BMEN 609 or EECE 605	Computational Neuroscience or Neuromuscular Engineering	3	X	X	
BMEN 610	Micro and Nano Neural Interfaces	3	X		
BMEN 611	Computational Modeling in Biomechanics	3	X	X	X
EECE 601 or EECE 602	Biomedical Engineering I or Biomedical Engineering II	3	X	X	X

1) Students are required to take two PhD lab rotation courses where each lab rotation is 1 credit (one lab rotation in MSFEA and one lab rotation in FM).
2) EPHD 310 can be replaced by another advanced level statistics course based on JPCC's approval.
3) Courses marked as "R" are required, and courses marked as "X" are possible elective options.

EECE 603	Biomedical Signal and Image Processing	3		X	X
EECE 633 or EECE 663 or EECE 667 or EECE 693	Data Mining or System Identification or Pattern Recognition or Neural Networks	3		X	
HUMR 305	Cell and Tissue Biology	3	R		
PHYL 300A	Pulmonary Physiology	1			R
PHYL 302	Cardiovascular Physiology	2			R

Free elective graduate courses: 6 credits additional elective courses. These courses should be taken based on the student's specific area of research as approved by the student's advisor.

Course Descriptions

BMEN 600 Biomedical Engineering Applications 3 cr.
Biomedical engineering is an interdisciplinary domain which applies principles of engineering to find solutions for biological and health problems. Biomedical engineering aims to improve our fundamental understanding of biological processes and develop approaches for optimized therapeutic/diagnostic healthcare procedures. The field of biomedical engineering involves the development of materials to replace or enhance the operation of damaged or malfunctioning biological entities, development of diagnostic and therapeutic tools, modeling of biological systems, signal processing and bioinformatics. This course will introduce students to biomedical engineering and provide insight into the various applications in the biomedical engineering field. The course will be divided into modules, and each will be given by a specialist in a certain biomedical engineering area.

BMEN 601/ MECH 635 Computational Modeling of Physiological Systems 3 cr.
This course focuses on the quantitative modeling of different physiological systems. It provides students with current concepts of the mathematical modeling, and different quantitative descriptions of cellular and organ physiology. At the subcellular/cellular level, we will examine mechanisms of regulation and homeostasis. At the system level, the course will cover basic aspects of anatomical and pathophysiological features of the nervous, neural, cardiovascular and respiratory systems. Several physiological processes are treated as case studies for increasing complexity in modeling dynamical systems. *Prerequisites: MATH 202 and PHYL 346, or consent of instructor.*

BMEN 602 Computational Modeling of Cardiovascular and Pulmonary Systems 3 cr.
The need for better understanding the mechanics and tools for computational modeling of cardiovascular and respiratory systems in healthy and diseased conditions is constantly increasing. This is a result of the enormous advances made in the science and engineering of both surgical and therapeutic medicine. This course covers the modeling and simulation of cardiovascular and respiratory systems. It will provide the students with a thorough understanding of the anatomy, physiology and mechanics of cardiovascular and respiratory systems as well as the computational tools for modeling and simulation of cardiac, circulatory and respiratory systems in healthy and diseased conditions.

BMEN 603/ CHEN 675 Tissue Engineering 3 cr.

In a world of aging population, an ever-increasing demand for improvement of healthcare services and need for replacement organs and tissues are arising. The limited pool of donors together with the problem of donor organ rejection is a strong driver for engineering tissues and other body parts. Tissue engineering is an interdisciplinary field that uses cells, biomaterials, biochemical (e.g. growth factors) and physical (e.g. mechanical stimulation) signals, as well as their combination to generate tissue-like structures. The goal of tissue engineering is to provide biological substitutes that can maintain, restore or improve the function of damaged organs in the body. This course will introduce interested students to the new field of tissue engineering and provide insight on cutting edge applications in this area.

BMEN 604/ CHEN 673 Engineering of Drug Delivery Systems 3 cr.

This course focuses on recent advances in the development of novel drug delivery systems. The fundamentals of drug delivery are discussed. Various strategies to tune and control the release of active agents for optimized therapeutic outcomes are explored. The course covers polymers and techniques used to produce drug nanoparticles, with specific examples of nanoparticle-based drug delivery systems. *Prerequisites: CHEN 314 and CHEN 411, or consent of instructor.*

BMEN 605 Biomedical Imaging 3 cr.

Biomedical imaging offers an unprecedented view into the structure and function of a living body, and as such plays an essential role in medical practice and research. This course will provide students with an overview of the key concepts underlying the primary diagnostic biomedical imaging modalities, including: ultrasound, x-ray, computed tomography, magnetic resonance and nuclear imaging. In particular, students will gain an understanding of the physical principles and theoretical bases governing the operation of each imaging modality, the technology that translates theory into practice, and the basic methods involved in image formation. Students will also learn the limitations of each imaging procedure, while being exposed to their vast applications in the clinic and research.

BMEN 606 Nanobiosensors 3 cr.

This course will provide a comprehensive analysis of the field of nanoengineering with a focus on biosensors including common modalities, basic theoretical considerations for sensor operation, physics of detection and applications in research and medical diagnostics. The course will cover the major types of electronic nanobiosensors for biological signal detection (potentiometric, amperometric, and mass based sensors) and their applications in the fields of neural engineering, DNA sequencing and cardiovascular early disease detection. The course will enable students to have a strong grasp of fundamentals of biosensor design, select sensors for various applications and evaluate new and emerging technologies. *Prerequisites: EECE 210 (or equivalent) and BIOL 210 (or equivalent); or consent of instructor.*

BMEN 607/ MECH 633 Biomechanics 3 cr.

A course on the study of the biomechanical principles underlying the kinetics and kinematics of normal and abnormal human motion. Emphasis is placed on the interaction between biomechanical and physiologic factors (bone, joint, connective tissue, and muscle physiology and structure) in skeleto-motor function and the application of such in testing and practice in rehabilitation. The course is designed for engineering students with no previous anatomy/physiology. *Prerequisites: CIVE 210, MECH 320 or CIVE 310; or consent of instructor.*

BMEN 608/ MECH 634 Biomaterial and Medical Devices 3 cr.

A course that examines the structure-property relationships for biomaterials and the medical applications of biomaterials and devices. The first part of the course focuses on the main classes of biomaterials, metal, ceramic, polymeric and composite implant materials, as well as on their interactions with the human body (biocompatibility). The second part of the course examines the various applications of biomaterials and devices in different tissue and organ systems such as orthopedic, cardiovascular, dermatologic and dental applications. Experts from the medical community will be invited to discuss the various applications. *Prerequisite: MECH 340 or consent of instructor.*

BMEN 609 Computational Neuroscience 3 cr.

The human brain, perhaps the most complex, sophisticated, and complicated learning system, controls virtually every aspect of our behavior. The central assumption of computational neuroscience is that the brain computes. What does that mean? Generally speaking, a computer is a dynamical system whose state variables encode information about the external world. In short, computation equals coding plus dynamics. Some neuroscientists study the way that information is encoded in neural activity and other dynamical variables of the brain. Others try to characterize how these dynamical variables evolve with time. The study of neural dynamics can be subdivided into two separate strands. One tradition, exemplified by the work of Hodgkin and Huxley, focuses on the biophysics of single neurons. The other focuses on the dynamics of networks, concerning itself with phenomena that emerge from the interactions between neurons. Therefore computational neuroscience can be divided into three sub-specialties: neural coding, biophysics of neurons, and neural networks. This course will introduce engineers, physicists, computational scientists, mathematicians and other audiences to the neurosciences from the cellular level and the network level as seen from computational lenses. *Prerequisites: BIOL 201 (or equivalent) and Math 202, or consent of instructor.*

BMEN 610 Micro and Nano Neural Interfaces 3 cr.

Neural interfaces are micro and nano devices that form the connection between the biological neural tissue and the external electronic devices. These devices are designed for mapping, assisting, augmenting, or repairing neural pathways. The course will focus on physical, chemical and neurophysiological principles of neural interfaces, theoretical and functional basis for their design, micro and nano fabrication techniques and applications in neural prosthesis for Brain Machine Interface. Topics covered in class will include; Neural Engineering, Brain Machine Interface, Microfabrication, Nanofabrication, Soft-lithography, Electrokinetics, Electrochemistry, Neural probes, Biocompatibility, Microelectrodes, NeuroMEMS (neuro microelectromechanical systems, BioMEMS (biomedical microelectromechanical systems).

BMEN 611 Computational Modeling in Biomechanics 3 cr.

This course provides students with a glimpse into the world of computational finite element modeling and simulation in biomechanics to investigate and solve biomedical problems. Students will take a journey through the processes involved in producing a computational finite element model in the biomedical field; starting at construction of model geometry, particularly from medical imaging data (CT/MRI), through to model creation, simulation and visualization using finite element analysis software (ANSYS Workbench). Students will also be exposed to a selection of experimental lab techniques in biomechanics and physiology to acquire data required for model development and validation. In pursuit of developing an appreciation for the areas covered, the course will incorporate a mix of theory, demonstrations, practice, real-world modeling applications and research seminars. In addition to skills gained in modeling and basic experimentation, the course will provide students with an opportunity to enhance vital skills in scientific writing and oral communication.

BMEN 671 PhD Lab Rotation 1 cr.
PhD students in Biomedical Engineering are required take two laboratory rotations (1 credit each) in different faculty research laboratories within the MSFEA and/or FM. Students may also enroll in a third elective laboratory rotation. This aims to familiarize students with potential thesis mentors and expose them to different research environments.

BMEN 672 Hospital Lab Rotation 0 cr.
MS and PhD students in Biomedical Engineering are required to do a lab rotation in the Medical Engineering Department at AUB Medical Center (AUBMC). This aims to familiarize students with the typical activities and responsibilities of a biomedical engineer in a working environment and expose them to different equipment and tools.

BMEN 673L Biomedical Engineering Lab 1 cr.
This laboratory course aims to introduce students to the practical issues in the areas of biomedical instrumentation design and biological signal processing. A particular emphasis will be placed on signal transduction, electronic circuit design for recording and conditioning physiological signals. The lab will introduce hand-on laboratory experiments on biomedical sensors, analog signal amplifiers and filters, digital acquisition and transmission, and basic digital filtering. In addition, some experiments cover topics that demonstrate the various levels of complexity that characterize biological signals. Signal processing tools include spectral and cepstral analysis, de-noising and artifact removal, filter banks and wavelet decompositions, Hilbert transforms, and information-theoretic measures.

BMEN 675 Approved Experience 0 cr.

BMEN 796 Special Project in Biomedical Engineering 3 cr.

BMEN 797 Special Topics in Biomedical Engineering 1 cr.

BMEN 798 Special Topics in Biomedical Engineering 3 cr.

BMEN 799T MS Comprehensive Exam 0 cr.
Every term.

BMEN 799 MS Thesis 6 cr.
Every term. Prerequisite: BMEN 799T.

BMEN 980 Qualifying Exam Part I: Comprehensive Exam 0 cr.
Every term.

BMEN 981 Qualifying Exam Part II: Defense of Thesis Proposal 0 cr.
Every term. Prerequisite: BMEN 980.

BMEN 982 PhD Thesis 3 cr.
Every term. Taken while total required credit hours have been completed.

BMEN 983 PhD Thesis 6 cr.
Every term. Taken while total required credit hours have not been completed.

BMEN 984 PhD Thesis 9 cr.
Every term. Taken while total required credit hours have not been completed.

BMEN 985 PhD Thesis 12 cr.
Every term. Taken while total required credit hours have not been completed.

BMEN 986 PhD Thesis 0 cr.
Every term. Taken while total required credit hours have not been completed.

BMEN 987 PhD Thesis Defense 0 cr.
Every term. Prerequisite: BMEN 981.

BIOC 321 Nucleic Acids and Basic Genetics 15.0; 1 cr.
This course discusses the principles of nucleic acid structure and function in eukaryotes. It includes the information for basic genetics in terms of genome structure as well as the diversity of gene regulation. Required from MS and PhD students in biomedical Sciences. requires consent of coordinator for other graduate disciplines. *First term.*

BIOC 322 Protein Biochemistry 10.10; 1 cr.
This course deals with the biochemistry of proteins including their basic units, different structures, folding process and protein-protein interactions. It focuses on how changes at the structural level modify function. The course also covers the principles of protein purification and sequencing, and introduces students to protein database, molecular modeling and systems biology. Required from MS and PhD students in biomedical sciences. Requires coordinator approval for other graduate disciplines. *First term.*

BIOC 325 Receptors and Signal Transduction 25.10; 2 cr.
This course covers classical pathways involved in receptor signaling and activation of downstream targets and the molecular mechanisms involved. It deals with the inter- and intracellular communication, from the generation of signaling molecules through the cellular responses. Required from MS and PhD students in biomedical sciences. Requires consent of coordinator for other graduate disciplines. *First term.*

BIOC 326A Bioinformatics Tools and Applications in Genomics 1 cr.
This course will discuss the relationships among sequence, structure and function in biological networks, as well as advances in modeling of quantitative, functional and comprehensive genomics analyses. It will assess computational issues arising from high-throughput techniques recently introduced in biomedical sciences, and cover very recent developments in computational genomics, including genome structural variant discovery, epigenome analysis, cancer genomics and transcriptome analysis.

BIOM 385 Research Ethics 15.0; 1 cr.
This course introduces the fundamentals of responsible conduct of research, emphasizing the ethical practice of human research. The course recaps history of ethical principles, the development of research codes of conduct and ethical practices, familiarizes students with the different kinds of ethical issues that they might come across throughout their careers and allows scholars to reflect critically on what it means to be an ethical and responsible researcher. *Summer term.*

EECE 601 Biomedical Engineering I 3 cr.
This course includes an introduction to: general instrumentation configuration and performance of instrumentation systems; types and characteristics of transducers; sources and characteristics of bioelectric signals; types and characteristics of electrodes; temperature regulation and measurement; cardiovascular system, measurements and diagnostic equipment; blood instruments; patient care and monitoring; and electrical safety of medical equipment. *Prerequisites: BIOL 210 or BIOL 202 or PHYL 246, and EECE 210; or PHYS 228 and PHYS 228L; or consent of instructor.*

EECE 603 Biomedical Signal and Image Processing 3 cr.
Fundamentals of digital signal processing as implemented in biomedical applications. It provides a concise treatment of the tools utilized to describe deterministic and random signals as the basis of analyzing biological signals: data acquisition; imaging; denoising and filtering; feature extraction; modeling. The course is tightly coupled with a practical component through laboratory projects. Examples include the auditory system, speech generation, electrocardiogram, neuronal circuits and medical imaging. Students should have reasonable software skills in Matlab. *Prerequisites: STAT 230 and EECE 340, or equivalent; or consent of instructor.*

EECE 633 Data Mining 3 cr.
This course is an introduction to data mining. Data mining refers to knowledge discovery from huge amounts of data to find non-trivial conclusions. Topics will range from statistics to machine learning to database, with a focus on analysis of large data sets. The course will target at least one new data mining problem involving real data for which the students will have to find a solution. *Prerequisite: EECE 330 or consent of instructor.*

EECE 663 System Identification 3 cr.
This course introduces the basic mathematical tools to fit models into empirical input-output data. General time-series modeling and forecasting, such as stock prices, biological data and others. Topics include nonparametric identification methods: time and frequency response analysis; parametric identification: prediction error, least squares, linear unbiased estimation and maximum likelihood; convergence, consistency and asymptotic distribution of estimates; properties and practical modeling issues: bias distribution, experiment design and model validation.

EECE 667 Pattern Recognition 3 cr.
The course provides an overview of the algorithms used in machine learning. The course discusses modern concepts for model selection and parameter estimation, decision-making and statistical learning. Special emphasis will be given to regression and classification for a supervised mode of learning. Students will be assigned typical machine learning problems to investigate as projects.

EECE 693 Neural Networks 3 cr.
The course provides a comprehensive foundation to artificial neural networks and machine leaning with applications to pattern recognition and data mining; learning processes: supervised and unsupervised, deterministic and statistical; clustering; single layer and multilayer perceptrons; least-mean-square, back propagation and Al-Alaoui algorithms; radial-basis function networks; committee machines; principal component analysis; self-organizing maps; and current topics of interest.

EPHD 310 Basic Biostatistics 2.2; 3 cr.
An introductory biostatistics course that covers basic concepts in statistical methods. The course demonstrates methods of exploring, organizing and presenting data. The course presents the foundation of statistical inference from estimation, to confidence interval and testing of hypothesis. Applications include comparing population means or proportions via data obtained from paired or independent samples, one-way ANOVA. Also, it introduces simple linear regression, correlations, logistic regression and nonparametric methods for data analysis.

HUMR 305 Cell and Tissue Biology 30.33; 3 cr.
Consists of the first half of Basic Histology, HUMR 209, covering cells and tissues. Open to graduate students outside the department.

HUMR 310 Biomedical Research Techniques 1 cr.
(A, B, or C)
A guided laboratory course in research methods used in cell biology and physiology. HUMR 310A covers Cell Biology Techniques; HUMR 310B covers Genomics and Proteomics; HUMR 310C covers Mouse Models and In Vivo Studies. Used in cell biology and physiology.

HUMR 314 Research Seminar 0.32; 1 cr.
Presentation and discussion of timely research topics designated by members of the department.

PHYL 302 Cardiovascular Physiology 31.6; 2 cr.
Presents the cardiovascular system with clear reference to pathophysiological and clinical events. Didactic lectures and seminar sessions define physiological concepts and emphasize structure-function relationships. Laboratory sessions familiarize the student with instrumentation and techniques in the cardiovascular field. *Open to all graduate students in the department.*

PHYL 346 Human Physiology for Paramedical and Undergraduate Students 48; 4 cr.
Outlines fundamental principles of human physiology and the mechanisms governing the function of different body organs. *Prerequisites: BIOC 246 and BIOL 201 (or BIOL 210).*