

Medicin og Teknologi

Studieudvalget har diskuteret mulighederne for specialisering i Medicin og Teknologi og fundet det nødvendigt at inddele specialiceringsmulighederne i tre ret brede fagområder: (a) Signal- og modelbaseret diagnostik, (b) Radiologi og helsefysik, og (c) Biomekanik og biomaterialer. Formålet med denne opdeling er i første omgang at gøre det lettere at identificere det faglige grundlag, der skal være til stede inden en specialisering påbegyndes og at identificere de linjefag, der skal udgøre det substantielle i en given specialiseringsretning. Endvidere gør denne opdeling det lettere at definere behovet for undervisere med specielle fagkompetencer. For de studerende vil denne fagopdeling tydeliggøre nødvendigheden af gradvist at fokusere sit studium på specifikke emner, uden derved at forhindre en individuel studieplan, hvori indgår kurser fra andre fagområder.

De ovenfor nævnte fagområder spænder usædvanligt bredt indenfor ingeniør- og naturvidenskaberne. Derfor skal den adgangsgivende Bacheloruddannelse give et solidt grundlag indenfor matematik, fysik og kemi, humanbiologi og traditionelle ingeniørfag samt en introduktion til de mest dominerende fagområder indenfor Medicin og Teknologi: biomekanik, biomaterialer, bioelektricitet, bioinstrumentering, biosystemer og medicinsk billeddannelse (skraveret i nedenstående tabel).

Bachelorprogram						
Sem.	5 p.	10 p.	15 p.	20 p.	25 p.	30 p.
1	Matematik 1 (lineær algebra, calculus, vektornalyse, ordinære differentialligninger)		Intro. Medikoteknik	Fysiologiske målinger (KU)	Humanbiologi og Sygdomslære (KU)	
2			Grundlæggende kemi	Projektkursus i kemi		
3	Fysik 1 (mekanik og termodynamik)	Elektronik	Bioelektricitet	Biomekanik (KU)		Valgfri
4		Matematik 2	Signaler og lineære systemer 1	Transducere og måleteknik	Cellebiologi (KU)	Valgfri
5	Indledende statistik	Indledende medicinsk billeddannelse	Signaler og lineære systemer 2	Biomaterialer (KU)	Fysiologisk modellering (KU)	Hospitalskursus (KU)
6	Stokastiske signaler		Videnskabsteori	Bachelorprojekt		

Ovenstående tabel beskriver studieudvalgets forslag til Bachelordelen (1. – 6. sem.). Der er i videst muligt omfang forsøgt etableret en faglig sammenhæng på tværs af samtidige kurser. Dette eksemplificeres i 3. sem. hvor Biomekanik bygger på Mekanik (Fysik 1) og Bioelektricitet, som igen bygger på kendskab til elektriske analogier (Elektronik). Faglig progression er også etableret, hvor man f. eks. går fra en funktionel matematisk beskrivelse af cellers ionkanaler i kurset Bioelektricitet til en mere detaljeret biologisk beskrivelse i Cellebiologi. Der er på samme måde en faglig progression i signalbehandling og –analyse startende på 4. sem. med deterministiske signaler til 6. semesters behandling af stokastiske signaler.

Medikotekniske Bachelorkurser:

Introduktion til medikoteknik (5 p.): Introduktion til elementære signaler, spektralanalyse, signalfiltrering, analog-til-digital konvertering, bioelektroder, statistiske signalparametre, instrumentering til digital registrering af bioelektriske signaler og muskelkraft, programmering med LabVIEW og Matlab, problemformulering, projektplanlægning, gruppearbejde, rapportskrivning.

Bioelektricitet (5 p.): Udledning af Nernst og Goldman ligninger, parallel-konduktansmodellen, ionkanalers ulineære konduktans, modeller for aktionspotentialer, kabelligning for cylindriske celler, makroskopiske kildemodeller, ekstracellulære potentialer i isotropt og anisotropt væv, modellering af motoriske enhedspotentialer, aktionspotentialets udbredelse i hjertet, hjertedipolen, lead field teorien, Einthoven trekanten, elektrodekonfigurationer for EKG, det normale elektrokardiogram og de klassiske arrytmier. Elektrisk stimulation af exciterbare celler.

Biomekanik (10 p.): Vævsbiomekanik: bindevæv, knoglevæv, bruskvæv, sener og ledbånd, brudstyrke, belastningsgrænse, stivhed, elastisk modulus, hysteres, stress-relaxation, krybning. Muskelmekanik: Concentrisk / ekscentrisk kontraktion, længdespændings relation, force-velocity relation, momentarme, muskelarkitektur, isokinetiske kraftmålinger, HQ-ratio, concentrisk / ekscentrisk styrke. Bevægelsesanalyse: målemetoder, antropometri, kinematik, kinetic, mekanisk arbejde, ganganalyse, simulering og optimering af bevægelser. Modeller af anatomiske strukturer: CT, MRI, ultralyd, billedbehandling, finite element modellering af vævsegenskaber, statisk og dynamisk belastning af strukturer. Elektrofysiologi: overflade emg, intramuskulær emg, elektrisk stimulation af muskler og nerver.

Transducere og måleteknik (5 p.): Transducere til måling af bevægelse, kraft, flow, tryk og temperatur, bioelektroder, måling af blodtryk, måling af flow og blodvolumen, måling på det respiratoriske system, kemiske biosensorer, instrumentering til kemisk analyse, pacemakere, defibrillatorer, hemodialyse, ventilatorer, elektrisk sikkerhed.

Biomaterialer (5 p.): Metaller og metallegeringer, korrosion, Bioinert keramik, bionedbrydelig keramik, bioaktiv keramik, polymere, polymerdegradering, bionedbrydelige polymere, sterilization og overfladebehandling af polymere, kompositter og porøse materialer, biologiske biomaterialer (collagen), blod-interfacing implantater, led implantater, protese fixering, cellulær respons til biomaterialer, inflammation, sårheling, infektion, immunreaktioner, biologisk reaktion under materialenedbrydning, biokompatibilitetsafprøvning, eksempler med design kriterier.

Indledende medicinsk billeddannelse (5 p.): Ultralyd: transducere, billeddannelse, flowmåling. Røntgen (skygebilleder og snitbilleder (CT)): instrumentering og rekonstruktionsprincipper. Magnetisk resonansbilleddannelse (MRI): grundlæggende princip, instrumentering, databehandling, funktionel MRI. Positron emission tomografi (PET): virkemåde og instrumentering. Single photon emission computer tomografi (SPECT): princip og instrumentering.

Fysiologisk modellering 1 (5 p.): Modellering af cellers calciumdynamik, nyrefiltrering, insulin-glukose regulering, kapillærtransport, Krogh's cylinder, blodets strømningsmekanik, respiration, farmakokinetik, hemodialyse, enzymreaktorer.

Specialisering i Medicin og Teknologi:

Studieudvalget har identificeret nogle kurser, som man bør tage, uanset specialiseringsretning. Disse kurser fremgår af nedenstående table:

	5 p.	10 p.	15 p.	20 p.	25 p.	30 p.
7.						
8.	Patofysiologi 1 (KU)	Statistisk forsøgsplanlægning				
9.	Patofysiologi 2 (KU)	Kvalitetskontrol og validering				
10.	Eksamensprojekt					

Det fremgår af skemaet, at der er god plads til at sammensætte en studieplan, som afspejler den enkelte studerendes faglige interesser. For at opnå retningsbetegnelsen civilingeniør i Medicin og Teknologi skal man dog have opnået 90 point (60 kursus point + 30 point for eksamensprojekt) indenfor en på forhånd vedtaget gruppe af retningspointgivende kurser. I nedenstående tabel vises nogle af de kurser, studieudvalget mener bør indgå i denne kategori. Listen er ikke komplet.

Prioritet	Linjefag		
	Signal og modelbaseret diagnostik	Radiologi og helsefysik	Biomekanik og biomaterialer
1	Videregående signalbehandling	Medicinske billedsystemer	Biomekanik 2
2	Fysiologisk modellering 2	Helsefysik	Biomaterialer 2
3	Medicinske billedsystemer	Isotopteknik	Biosensorer
4	Ulineære systemer	Billedanalyse	Microdiagnostiske systemer
5	Audiologi	Fysiologisk modellering 2	Fysiologisk modellering 2

Kurserne i ovenstående tabel skal opfattes som et oplæg til diskussion. Der er ikke fra studieudvalgets side gjort anstrengelser for at definere det konkrete indhold i disse kurser.

Som inspiration til, hvad der kunne lægges i disse videregående kurser, er der på de næste sider lavet et kompendium af medikotekniske kurser ved tre af de største medikotekniske uddannelser i USA.

Eksempler på kurser i tre af de største medikotekniske uddannelser i USA:

Duke University (est. 1970)

Enrollment: Bachelors: 340, Masters: 3, Ph.D. 72, VIP: (12+12)

Undergraduate Courses:

201L. Electrophysiology. The electrophysiology of excitable cells from a quantitative perspective. Topics include the ionic basis of action potentials, the Hodgkin-Huxley model, impulse propagation, source-field relationships, and an introduction to functional electrical stimulation. Students choose a relevant topic area for detailed study and report. Not open to students who have taken Biomedical Engineering 101L or equivalent. 3 units; 4 units with laboratory. Instructor: Barr, Henriquez, or Krassowska. Variable credit.

204. Measurement and Control of Cardiac Electrical Events. Design of biomedical devices for cardiac application based on a review of theoretical and experimental results from cardiac electrophysiology. Evaluation of the underlying cardiac events using computer simulations. Examination of electrodes, amplifiers, pacemakers, and related computer apparatus. Construction of selected examples. Prerequisites: Biomedical Engineering 101L and 163L or equivalents. Instructor: Wolf. 3 units.

205L. Microprocessors and Digital Instruments. Design of microcomputer-based devices including both hardware and software considerations of system design. Primary emphasis on hardware aspects, including a progression through initial design, prototype construction in the laboratory, testing of prototypes to locate and correct faults, and final design evaluation. Evaluation includes examination of complexity, reliability, and cost. Design and construction oriented toward biomedical devices or instruments that include dedicated microcomputers, usually operating in real time. Prerequisites: Biomedical Engineering 163L, 164L and Engineering 53L or equivalents. Instructor: Staff. 4 units.

206. Elasticity. Linear elasticity will be emphasized including concepts of stress and strain as second order tensors, equilibrium at the boundary and within the body, and compatibility of strains. Generalized solutions to two and three dimensional problems will be derived and applied to classical problems including torsion of noncircular sections, bending of curved beams, stress concentrations and contact problems. Applications of elasticity solutions to contemporary problem in civil and biomedical engineering will be discussed.

Prerequisites: Undergraduate partial differential equations or equivalent math course, Introductory Mechanics of Solids. Instructor: Meyers. 3 units. C-L: Civil Engineering 206

207. Transport Phenomena in Biological Systems. An introduction to the modeling of complex biological systems using principles of transport phenomena and biochemical kinetics. Topics include the conservation of mass and momentum using differential and integral balances; rheology of Newtonian and non-Newtonian fluids; steady and transient diffusion in reacting systems; dimensional analysis; homogeneous versus heterogeneous reaction systems. Biomedical and biotechnological applications are discussed. Instructor: Katz, Truskey, or Yuan. 3 units. C-L: Civil

Engineering 207, Mechanical Engineering and Materials Science 207

208. Theoretical and Applied Polymer Science. 3 units. C-L: see Mechanical Engineering and Materials Science 211

209. Kinetics and Reactor Design. 3 units. C-L: see Civil Engineering 209

211. Theoretical Electrophysiology. Advanced topics on the electrophysiological behavior of nerve and striated muscle. Source-field models for single-fiber and fiber bundles lying in a volume conductor. Forward and inverse models for EMG and ENG. Bidomain model. Model and simulation for stimulation of single-fiber and fiber bundle. Laboratory exercises based on computer simulation, with emphasis on quantitative behavior and design. Readings from original literature. Prerequisite: Biomedical Engineering 101L or 201L or equivalent. Instructor: Barr or Krassowska. 4 units.

212. Theoretical Electrocardiography. Electrophysiological behavior of cardiac muscle. Emphasis on quantitative study of cardiac tissue with respect to propagation and the evaluation of sources. Effect of junctions, inhomogeneities, anisotropy, and presence of unbounded extracellular space. Bidomain models. Study of models of arrhythmia, fibrillation, and defibrillation. Electrocardiographic models and forward simulations. Laboratory exercises based on computer simulation, with emphasis on quantitative behavior and design. Readings from original literature. Prerequisite: Biomedical Engineering 101L or 201L or equivalent. Instructor: Barr. 4 units.

213L. Nonlinear Dynamics in Electrophysiology. Electrophysiological behavior of excitable membranes and nerve fibers examined with methods of nonlinear dynamics. Phase-plane analysis of excitable membranes. Limit cycles and the oscillatory behavior of membranes. Phase resetting by external stimuli. Critical point theory and its applications to the induction of rotors in the heart. Theory of control of chaotic systems and stabilizing irregular cardiac rhythms. Initiation of propagation of waves and theory of traveling waves in a nerve fiber. Laboratory exercises based on computer simulations, with emphasis on quantitative behavior and design. Readings from original literature. Prerequisite: Biomedical Engineering 101L or 201L or equivalent. Instructor: Krassowska. 4 units.

215. Biomedical Materials and Artificial Organs. Chemical structures, processing methods, evaluation procedures, and regulations for materials used in biomedical applications. Applications include implant materials, components of ex vivo circuits, and cosmetic prostheses. Primary emphasis on polymer-based materials and on optimization of parameters of materials which determine their utility in applications such as artificial kidney membranes and artificial arteries. Prerequisite: Biomedical Engineering 83L, Chemistry 151L or Mechanical Engineering 83L or consent of instructor. Instructor: Reichert. 3 units. C-L: Mechanical Engineering and Materials Science 215

216. Transport Phenomena in Cells and Organs.

Applications of the principles of mass and momentum transport to the analysis of selected processes of biomedical and biotechnological interest. Emphasis on the development and critical analysis of models of the particular transport process. Topics include: reaction-diffusion processes, transport in natural and artificial membranes, dynamics of blood flow, pharmacokinetics, receptor-mediated processes and macromolecular transport, normal and neoplastic tissue. Prerequisite: Biomedical Engineering 207 or equivalent. Instructor: Truskey or Yuan. 3 units.

220L. Introduction to Biomolecular Engineering. Structure of biological macromolecules, recombinant DNA techniques, principles of and techniques to study protein structure-function. Discussion of biomolecular design and engineering from the research literature. Linked laboratory assignments to alter protein structure at the genetic level. Expression, purification, and ligand-binding studies of protein function. Consent of instructor required. Instructor: Chilkoti. 3 units.

222. Principles of Ultrasound Imaging. Propagation, reflection, refraction, and diffraction of acoustic waves in biologic media. Topics include geometric optics, physical optics, attenuation, and image quality parameters such as signal-to-noise ratio, dynamic range, and resolution. Emphasis is placed on the design and analysis of medical ultrasound imaging systems. Prerequisites: Mathematics 111 and Physics 52L. Instructor: von Ramm. 3 units.

228. Laboratory in Cellular and Biosurface Engineering. Introduction to common experimental and theoretical methodologies in cellular and biosurface engineering. Experiments may include determination of protein and peptide diffusion coefficients in alginate beads, hybridoma cell culture and antibody production, determination of the strength of cell adhesion, characterization of cell adhesion or protein adsorption by total internal reflection fluorescence, and Newtonian and non-Newtonian rheology. Laboratory exercises are supplemented by lectures on experiment design, data analysis, and interpretation. Instructor: Truskey. 3 units.

230. Tissue Biomechanics. Introduction to the mechanical behaviors of biological solids and fluids with application to tissues, cells and molecules of the musculoskeletal and cardiovascular systems. Topics to be covered include static force analysis and optimization theory, biomechanics of linearly elastic solids and fluids, anisotropic behaviors of bone and fibrous tissues, blood vessel mechanics, cell mechanics and behaviors of single molecules. Emphasis will be placed on modeling stress-strain relations in these tissues, and experimental devices used to measure stress and strain. Student seminars on topics in applied biomechanics will be included. Prerequisites: Biomedical Engineering 110L or Engineering 75L or equivalent. Instructor: Meyers and Setton. 3 units.

231. Intermediate Biomechanics. Introduction to solid and orthopaedic biomechanical analyses of complex tissues and structures. Topics to be covered include: spine biomechanics, elastic modeling of bone, linear and quasi-linear viscoelastic properties of soft tissue (for example, tendon and ligament), and active tissue responses (for example, muscle). Emphasis will be placed on experimental techniques used to evaluate these tissues. Student seminars on topics in applied biomechanics will be included. Prerequisites: Biomedical Engineering 110L or Engineering 75L or equivalent. Instructor: Myers or Setton. 3 units.

232L. Biomedical Instrumentation. A study of the basic principles of biomedical electronics and measurements with emphasis on the operational performance and selection of transducers, instruments, and systems for biomedical data acquisition and processing. Selected laboratory work emphasizes the measurement of specific physiologic events. Students will design and build a working medical instrument. Consent of instructor required. Not open to students who have taken Biomedical Engineering 164L. Instructor: Wolf. 4 units.

233. Modern Diagnostic Imaging Systems. The underlying concepts and instrumentation of several modern medical imaging modalities. Review of applicable linear systems theory and relevant principles of physics. Modalities studied include X-ray radiography (conventional film-screen imaging and modern electronic imaging), computerized tomography (including the theory of reconstruction), and nuclear magnetic resonance imaging. Prerequisite: junior or senior standing. Instructor: Hsu, Smith, or Trahey. 3 units.

235. Acoustics and Hearing. The generation and propagation of acoustic (vibrational) waves and their reception and interpretation by the auditory system. Topics under the heading of generation and propagation include free and forced vibrations of discrete and continuous systems, resonance and damping, and the wave equation and solutions. So that students may understand the reception and interpretation of sound, the anatomy and physiology of the mammalian auditory system are presented; and the mechanics of the middle and inner ears are studied. Prerequisites: Mathematics 111 and Physics 52L or equivalents. Instructor: Collins or Trahey. 3 units. C-L: Electrical and Computer Engineering 284

237. Biosensors. Biosensors are defined as the use of biospecific recognition mechanisms in the detection of analyte concentration. The basic principles of protein binding with specific reference to enzyme-substrate, lectin-sugar, antibody-antigen, and receptor-transmitting binding. Simple surface diffusion and absorption physics at surfaces with particular attention paid to surface binding phenomena. Optical, electrochemical, gravimetric, and thermal transduction mechanisms which form the basis of the sensor design. Prerequisites: Biomedical Engineering 83L and consent of instructor. Instructor: Reichert. 3 units.

239. Cell Transport Mechanisms. Analysis of the migration of cells through aqueous media. Focus on hydrodynamic analysis of the directed self-propulsion of individual cells, use of random walk concepts to model the nondirected propulsion of individual cells, and development of kinetic theories of the migrations of populations of cells. Physical and chemical characteristics of the cells' environments that influence their motion, including rheologic properties and the presence of chemotactic, stimulatory, or inhibitory factors. Cell systems include mammalian sperm migration through the female reproductive tract, protozoa, and bacteria. Emphasis on mathematical theory. Experimental designs and results. Consent of instructor required. Instructor: Katz. 3 units.

241. Artificial Intelligence in Medicine. Basic concepts of artificial intelligence (AI) and in-depth examination of medical applications of AI. Knowledge of heuristic programming; brief examination of classic AI programming languages (LISP and PROLOG) and AI programming; rule-based systems and cognitive models. Instructor: Staff. 3 units.

243. Introduction to Medical Informatics. An introduction to medical informatics: an in-depth study of the use of computers in biomedical applications. Hardware, software, and applications programming. Data collection, analysis, and presentation studied within application areas such as patient monitoring, computer-based medical records, computer-aided decision making, computer-aided instruction, quality assurance laboratory systems, wave form analysis, hospital information systems, and medical information systems. Instructor: Staff. 3 units.

246. Computational Methods in Biomedical Engineering. Introduction to practical computational methods for data analysis and simulation with a major emphasis on implementation. Methods include numerical integration and differentiation, extrapolation, interpolation, splining FFTs, convolution, ODEs, and simple one- and twodimensional PDEs using finite differencing. Introduction to concepts for optimizing codes on a CRAY-YMP. Examples from biomechanics, electrophysiology, and imaging. Project work included and students must have good working knowledge of Unix, Fortran, or C. Intended for graduate students and seniors who plan on attending graduate school. Prerequisite:

Engineering 53L or equivalent, Mathematics 111 or equivalent, or consent of instructor. Instructor: Henriquez. 3 units.

248. Tissue Engineering. This course will serve as an overview of selected topics and problems in the emerging field of tissue engineering. General topics include cell sourcing and maintenance of differentiated state, culture scaffolds, cell-biomaterials interactions, bioreactor design, and surgical implantation considerations. Specific tissue types to be reviewed include cartilage, skin equivalents, blood vessels, myocardium and heart valves, and bioartificial livers. Consent of instructor required. Instructor: Niklason. 3 units.

260. Devices for People with Disabilities. Design of custom devices to aid disabled individuals. Students will be paired with health care professionals at local hospitals who will supervise the development of projects for specific clients. Formal engineering design principles will be emphasized; overview of assistive technologies, patent issues, engineering ethics. Oral and written reports will be required. Selected projects may be continued as independent study. Prerequisite: Biomedical Engineering 164L or equivalent, or consent of instructor. Instructor: Bohs or Goldberg. 3 units.

264L. Medical Instrument Design. General principles of signal acquisition, amplification processing, recording, and display in medical instruments. System design, construction, and evaluation techniques will be emphasized. Methods of real-time signal processing will be reviewed and implemented in the laboratory. Each student will design, construct, and demonstrate a functional medical instrument and collect and analyze data with that instrument. Formal write-ups and presentations of each project will be required. Prerequisite: Biomedical Engineering 164L or equivalent or senior standing. Instructor: S. Smith, Trahey, or Wolf. 4 units.

265. Advanced Topics in Biomedical Engineering. Advanced subjects related to programs within biomedical engineering tailored to fit the requirements of a small group. Consent of instructor required. Instructor: Staff. 3 units.

270. Introduction to Biomedical Optics. This introductory class examines the basic theory of laser light interaction with tissue, and the diagnostic and therapeutic uses of lasers in medicine. The class is divided into three parts: (I) Tissue Optics; (II) Laser- Tissue Interactions; and (III) Medical Applications of Lasers. Prerequisites: Biomedical Engineering 170, or consent of instructor. Instructor: Hooper. 3 units.

For Graduates

301. Biomolecular and Tissue Engineering Seminar. Current topics in biomolecular and tissue engineering. Theory and practice. Weekly seminar series. Instructor: Reichert or Truskey. 1 unit.

302. Biomolecular and Tissue Engineering Seminar. Current topics in biomolecular and tissue engineering. Theory and practice. Weekly seminar series. Instructor: Reichert or Truskey. 1 unit.

310. BME Graduate Seminars. Two semester, weekly seminars series required of all BME graduate students. Students are exposed to the breadth of research topics in BME via seminars given by BME faculty, advanced graduate students, and invited speakers. At the end of each semester students are required to write a synopsis of the seminars attended. More than three unexcused absences will result in a failing grade. Instructor: Staff. 1 unit.

311. BME Graduate Seminars. Two semester, weekly seminars series required of all BME graduate students. Students are exposed to the breadth of research topics in BME

via seminars given by BME faculty, advanced graduate students, and invited speakers. At the end of each semester students are required to write a synopsis of the seminars attended. More than three unexcused absences will result in a failing grade. Instructor: Staff. 1 unit.

320. Medical Ultrasound Transducers. A study of the design, fabrication, and evaluation of medical ultrasound transducers. Topics include wave propagation in piezoelectric crystals, Mason and KLM circuit models, linear arrays and twodimensional arrays, piezoelectric ceramic/epoxy composite materials, piezoelectric polymers, and photo-acoustic materials. Consent of instructor required. Instructor: S. Smith. 3 units.

329. Continuum Biomechanics. Introduction to conservation laws and thermodynamic principles of continuum mechanics with application to tissues of the musculoskeletal and cardiovascular systems. Topics cover nonlinear and anisotropic behaviors of solids and fluids. Emphasis on the application of hyperelastic constitutive formulations to determination of stress and strain fields in deformations of calcified tissues (for example, cortical and trabecular bone), soft tissues (for example, ligament, cartilage, cornea, intervertebral disc, left ventricle, aorta), and biological fluids (for example, mucus, synovial fluid, polymer solutions). Tensor fields and indicial notation. Prerequisites: Biomedical Engineering 110L or Engineering 75L or equivalent, and Mathematics 111 or equivalent. Instructor: Setton. 3 units.

330. Finite Element Method for Biomedical Engineers. The finite element method with an emphasis on applications to biomedical engineering. Several detailed examples illustrate the finite element analysis process, which includes setting up a mathematical description of the problem, putting it into a form suitable for finite element solution, solving the discretized problem, and using advanced computer codes to check the correctness of the numerical results. Consent of instructor required. Instructor: Staff. 3 units.

331. Viscoelasticity. Viscoelasticity of hard and soft tissue solids and composite structures. Linear and nonlinear one-dimensional viscoelastic behavior, internal damping, and three-dimensional viscoelasticity. Approximation techniques for determination of viscoelastic constitutive equations from experimental data. Mathematical formulations for the characterization of the dynamic behavior of biologic structures. Consent of instructor required. Instructor: Myers. 3 units.

333. Biomedical Imaging. A study of the fundamentals of information detection, processing, and presentation associated with imaging in biology and medicine. Analysis of coherent and incoherent radiation and various image generation techniques. Design and analysis of modern array imaging systems as well as systems. Instructor: von Ramm. 3 units.

340. Mechanics of Multiphase Biological Tissues. Introduction to constitutive modeling of multiphase mixtures with application to biological tissues (for example, skin, cornea, ligament, cartilage, intervertebral disc). Fundamental conservation laws and thermodynamic principles of the theory of mixtures will be reviewed. Development of constitutive equations for mixtures containing inviscid and viscous fluids, as well as hyperelastic, viscoelastic, and charged solids. Emphasis on solution methods required to determine the stress, strain, and flow fields in boundary value problems of simplified geometries, including problems for contact of two bodies. A knowledge of tensor fields, indicial notation, and partial differential equations is required. Prerequisite: Mathematics 114 or equivalent, and Biomedical Engineering 229 or consent of instructor. Instructor: Setton. 3 units.

Johns Hopkins University (est. 1970)

Enrollment: Bachelors: 361, Masters: 21, Ph.D. 70, VIP: (19+33)

580.110 (E) Models for Life

This course introduces biomedical engineering freshmen to an orderly method for analyzing and modeling biological systems, using only corequisite freshman mathematics and physics. Working with an instructor in small groups, students will learn to develop mathematical models of biological systems and design the experiments necessary to test these models. Then, they will conduct experiments in small teams and compare their results with those predicted by their models. Students will learn the introductory computer skills necessary to simulate their mathematical models, analyze their experimental data, and plot their results. Freshman BME students taking physics or with physics AP credit only. Schramm 2 credits fall

580.111-112 (E,N) Design Team—Freshman

A two-semester course sequence where freshmen work with groups of BME upperclassmen mentors, and learn to use engineering principles to solve design problems that are biological, physiological, and/or medical. Freshmen are expected to use the informational content being taught in calculus, physics, and chemistry and apply this knowledge to the solution of practical problems encountered in biomedical engineering.

Shoukas, Allen 2 credits fall, 3 credits spring.

580.202 (E,S) Biomedical Engineering in the Real World

A series of weekly lectures to inform students about careers in biomedical engineering and to discuss technological, social, ethical, legal, and economic issues relevant to the profession. Topics include academic careers in biomedical engineering; biomedical engineering in industry (large corporations to sole entrepreneurship); health care delivery; ethical issues; legal issues (patenting, licensing, product liability); standards and government regulations; and economic issues in biomedical engineering industry (start-up companies, global businesses).

This course is open to all students.

Popel 1 credit spring

580.211-212 (E,N) Design Team—Sophomore

Sophomore-level version of 580.111-112. Permission of course directors required.

Shoukas, Allen 3 credits per semester

580.221 (N) Molecules and Cells

An introduction to modern molecular and cellular biology in the context of potential biomedical engineering applications.

Topics covered: reactions between molecules, including receptor-ligand and antigen-antibody specificity, protein structure, enzyme catalysis, genetic information, protein processing and secretion, cell physiology and cell functions. Advanced quantitative treatment including multistate kinetics, Monte Carlo simulations of biochemical reactions, and transport phenomena. Prerequisites: 030.101 Introductory Chemistry and 030.104 Introductory Organic Chemistry.

Kuo, Chen 4 credits

580.222 (E) Biomedical Circuits Signals and Systems

An introduction to linear systems and linear systems analysis. Topics include generalized effort and flow variables, duality, first and second order systems, linear timeinvariant discrete and continuous systems, Fourier series, Fourier transforms. Biological examples will be given of electrical, mechanical, hydrodynamic, thermal and chemical

systems. Prerequisite: 171.102 Physics II. Corequisite: 110.302 Differential Equations.

Tung, Miller 4 credits

580.302 (E,S) Careers in Biomedical Engineering

See description for 580.202. This course is designed for upperclassmen who wish to meet with weekly speakers to discuss careers issues.

Popel, Sachs 1 credit spring

580.311-312 (E,N) Design Team—Junior

A two semester course sequence where juniors and seniors work with a team leader and a group of BME freshmen and sophomores, to solve open-ended problems in biomedical engineering. Upperclassmen are expected to apply their general knowledge and experience, and their knowledge in their concentration area, to teach lower classmen and to generate the solution to practical problems encountered in biomedical engineering. Permission of course directors required.

Shoukas, Allen 3 credits per semester

580.402 (E) Neuroengineering

See description for 580.702.

Thakor 3 credits spring

580.411-412 (E,N) Design Team—Senior

Senior-level version of 580.311-312. Permission of course directors required.

Shoukas, Allen 3 credits per semester

580.413-414 (E,N) Design Team—Leader

A two-semester sequence where leaders direct a team of undergraduate biomedical engineering students in a series of design problems. Prior design team experience and permission of course directors required.

Shoukas, Allen 4 credits per semester

580.421 (E,N) Physiological Foundations I

A quantitative, model-oriented investigation of the cardiovascular system. Topics are organized in three segments. (1) Molecular/cellular physiology, including electrical signaling and muscle contraction. (2) Systems cardiovascular physiology, emphasizing circuit-diagram analysis of hemodynamics. (3) Cardiovascular horizons and challenges for biomedical engineers, including heart failure and its investigation/treatment by computer simulation, by gene-array analysis, by stem-cell technology, and by mechanical devices (left-ventricular assist and totalheart

replacement). Prerequisites: 580.221 Molecules and Cells, 580.222 BME Signals and Systems, 110.302 Differential Equations. Corequisite: 580.423 Physiological Foundations Laboratory I.

Yue, Staff 4 credits

580.422 (E,N) Physiological Foundations for Biomedical Engineering II

A quantitative, model-oriented approach to the study of the nervous system. Topics include functional anatomy of the central and autonomic nervous systems, neurons and networks, learning and memory, structure and function of the auditory and visual systems, motor systems, and neuroengineering.

Prerequisites: 580.221 Molecules and Cells, 580.222 BME Signals and Systems, 110.302 Differential Equations, 580.421 Physiological Foundations I. Corequisite:

580.424 Physiological Foundations Laboratory II.
Shadmehr, Staff 4 credits

580.423-424 Laboratory in Physiological Foundations for Biomedical Engineering I, II

A two-semester laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems.

Corequisites: 580.421-422.

Allen, Staff 2 credits

580.425 (E,N) Ionic Channels in Excitable Membranes

Ionic channels are key signaling molecules that support electrical communication throughout the body. As such, these channels are a central focus of biomedical engineering as it relates to neuroscience, computational biology, biophysics, and drug discovery. This course introduces the engineering (stochastic and mathematical models) and molecular strategies (cloning and expression) used to understand the function of ionic channels. The course also surveys key papers that paint the current picture of how channels open (gating) and conduct ions (permeation). Biological implications of these properties are emphasized throughout. Finally, the course introduces how optical (fluorescence methods) and electrophysiological methods (patch clamp) now promise to revolutionize understanding of ionic channels. This course can be viewed as a valuable partner of Models of Physiological Processes in the Neuron (580.439). Prerequisites: 580.421-422, or equivalent introductory

biology. Recommended: differential equations, linear algebra, signals, and elementary probability.

Yue 3 credits spring/odd years

580.430 (E,N) Cardiovascular Systems Mechanics

This course considers quantitative aspects of circulatory mechanics with an emphasis on the overall system. Integration and control of circulatory function are emphasized; models of integrative function are reviewed. Course meetings consist of lectures by faculty and guests.

Prerequisites:

580.421-422 or equivalent, 520.213 Circuits, 520.214 Signals and Systems, and 520.454 Control Systems, or permission of instructor.

Shoukas 3 credits fall/even years

580.431 (E,N) Biomechanics and Motor Control

See description for 580.631.

Shadmehr 3 credits fall

580.435 (E,N) Bioelectromagnetic Phenomena

This course reviews theoretical concepts and experimental approaches used to characterize electric, magnetic, and electromagnetic phenomena that arise in biological tissues. Topics include the passive and active behavior of cell membranes, volume conductor models of cells and tissues, the bidomain model, bioelectric and biomagnetic measurements, electric and magnetic stimulation, and impedance plethysmography and tomography.

Prerequisites: 110.202, 110.302 (or 550.291), 520.213, 520.219, 520.214, 580.421 or equivalent.

Tung 3 credits fall/odd years

580.438 (E,N) Cell Mechanics and Motility

See description for 580.638

Prerequisites: Either 580.421 or 020.305-306.

Kuo 3 credits spring/odd years

580.439 (E,N) Models of Physiological Processes in the Neuron

Single-neuron modeling, emphasizing the use of computational models as links between the properties of neurons at several levels of detail. Topics include thermodynamics of ion flow in aqueous environments, biology and biophysics of ion channels, gating, nonlinear dynamics as a way of studying the collective properties of

channels in a membrane, synaptic transmission, integration of electrical activity in multi-compartment dendritic tree models, and properties of neural networks.

Students will study the properties of computational models of neurons; graduate students will develop a neuron model using data from the literature. Prerequisites: 580.421-422 or equivalent, 110.302 Differential Equations, or 500.303 Applied Mathematics I or equivalent.

Recommended: 520.213 Circuits.

Young 4 credits fall

580.440 (E) Biomedical Polymers

The course focuses on biomedical applications of synthetic polymers. After a brief review of the synthesis and characterization of different classes of biomedical polymers, examples of the use of these polymers in pharmaceutical, cardiovascular, ophthalmologic, and orthopedic areas will be studied. Prerequisite: polymer background.

Leong 3 credits spring/even years

580.441 (E,N) Cellular Engineering

Lectures provide an overview of molecular biology fundamentals, an extensive review on extracellular matrix and basics of receptors, followed by topics on cell-cell and cell-matrix interactions at both the theoretical and experimental levels. Subsequent lectures will cover the effects of physical (shear, stress, strain), chemical (cytokins, growth factors), and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Material on cell-cycle, apoptosis, metabolic engineering and gene therapy will also be incorporated into the course. Prerequisite: 580.221 Molecules and Cells.

Konstantopoulos, Yarema 3 credits fall

580.442 (E,N) Tissue Engineering

Lectures provide an overview of tissue structure and function, followed by a review of biomaterials (collagen) and cell-biomaterial interactions. Subsequent lectures will cover fundamentals of stem cell biology, and discuss in depth, applications of tissue engineering to specialized tissues and organs, including skin; muscular skeletal system (bone, cartilage, tendon, and ligament); cardiovascular system (vascular grafts, blood substitutions, cardiac patch, and heart valve); nervous system (peripheral and central nervous systems); liver; pancreas, and kidney. Prerequisite: 580.221 Molecules and Cells.

Elisseeff, Leong 3 credits spring

580.450 (E,N) Mechanics of Living Tissues

Review of continuum mechanics for large, finite deformations. Overview of constitutive properties of tissues, including viscoelasticity. Methods of mechanically testing tissues. The finite element method as applied to physiological problems. Mechanics of specific tissues and organs, e.g., heart, lung, bone. Prerequisites: 110.201 Linear Algebra, 560.206 Engineering Mechanics of Solids, 530.405 Mechanics of Solids and Structures, or equivalent.

Douglas, Spector 3 credits spring/even years

580.452 (E,N) Cellular and Tissue Engineering Laboratory

This laboratory course will consist of three experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction.

Elisseeff 2 credits spring

580.455 (E,N) Introduction to Orthopaedic Biomechanics

An introduction to the field of orthopaedic biomechanics. This course will cover the structure and function of the musculoskeletal system, including detailed discussions

on the material properties of bone, ligament, tendon, articular cartilage, and muscle. Other topics will include bone remodeling, viscoelasticity, and the estimation of joint forces using equilibrium methods. Prerequisite: 560.201 Statics or equivalent.

Kleinberger 3 credits fall/odd years

580.460 (E,N) Physiological Fluid Mechanics

Basic concepts and problems of fluid and solid mechanics and rheology are introduced and applied to the analysis of blood flow in the macro- and microcirculation, and to other physiological flows. Analysis of mathematical models is combined with discussions of physiological mechanisms. Prerequisite: 110.302 Differential Equations.

Popel 3 credits spring/odd years

580.461 (E,N) Biological Transport

Basic principles and mechanisms of mass transport in multicomponent systems with application to biological phenomena. Examples of physiological mass and heat transfer. Mathematical models of pharmacokinetics and membrane transport. Students will carry out a modeling project of biological transport systems. Prerequisite: 110.302 Differential Equations.

Popel 3 credits fall/odd years

580.471 (E) Principles of the Design of Biomedical Instrumentation

This core design course will cover lectures and hands-on labs. The material covered will include fundamentals of biomedical sensors and instrumentation, FDA regulations, designing with electronics, biopotentials and ECG amplifier design, recording from heart, muscle, brain, etc., diagnostic and therapeutic devices (including pacemakers and defibrillators), applications in prosthetics and rehabilitation, and safety. The students will also carry out design challenge projects, individually or in teams. Prerequisite: 520.345.

Thakor 4 credits fall

580.472 (E) Medical Imaging Systems

An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Prerequisite: 520.214. (Co-listed as 520.432.)

Prince 3 credits spring

580.473 (E,N) Magnetic Resonance in Medicine

This course provides the student with a complete introduction to the physical principles, hardware design, and signal processing used in magnetic resonance imaging and magnetic resonance spectroscopy. The course is designed for senior or graduate students who wish to pursue research in magnetic resonance. Prerequisite: 520.214 Signals and Systems.

Atalar 3 credits fall

580.482 (E,N) Computational Modeling of the Cardiac Myocyte

See description for 580.682.

Winslow 3 credits spring

580.495 Microfabrication Laboratory

This laboratory course introduces the principles used in the construction of microelectronic devices, sensors, and micromechanical structures. Students will work in the laboratory on the fabrication and testing of a device. Accompanying lecture material covers basic processing steps, design and analysis CAD tools, and national foundry services. Prerequisite: permission of instructor. (Co-listed as 520.495.)

Andreou 4 credits fall/even years

580.498-499 (E) Capstone Design

Yearlong course to conceive and implement a biomedical engineering design project. Projects will be proposed and sponsored by the faculty and scientists of the university

as well as industry. Laboratory and industrial site visits are also incorporated to the course format.

Thakor, Staff 4 credits per term

580.541-543 Junior/Senior Independent Study in Biomedical Engineering

Directed readings or other literature research under the direction of any BME faculty member. Prerequisite: junior or senior standing.

Staff up to 3 credits per term

580.571 (E) Honors Instrumentation

Students enrolled jointly in 580.471 and 580.571 will not be required to take exams. Instead, students will develop a term paper and patent application and carry out a hands-on individual or team project throughout the semester and the intersession. Previous projects include design of EEG amplifier, voltage clamp and patch clamp, vision aid of blind, pacemaker/defibrillator, sleep detection and alert device, glucose sensor and regulation, temperature controller, eye movement detection and device control, ultrasound ranging and tissue properties, impedance plethysmography, lie detector, blood alcohol detector, pulse oximeter, etc. Corequisite: must be enrolled in 580.471. Thakor 2 credits fall and intersession

580.580 (E) Biomedical Engineering Senior Design Project

Independent or team design project to design and evaluate a system. The design should demonstrate creative thinking and experimental skills, and must draw upon advanced topics of biomedical and traditional engineering. Project proposal and permission of the undergraduate program director are required.

Allen 3 credits

Graduate Courses

580.601-602 Seminar in Biomedical Engineering

Weekly seminar in which faculty, staff, graduate students, and outside speakers discuss topics of current research interest.

Staff 1 hour

580.603-604 Topics in Biomedical Engineering

A series of informal seminars in which faculty of the department discuss their research interests; emphasis is on discussion between faculty and students. The purpose is to introduce graduate students to research opportunities. Open to doctoral students in Biomedical Engineering; others by permission.

Schramm 1 hour

580.625-626 Structure and Function of the Auditory and Vestibular Systems

Physiological mechanisms of hearing and balance. Topics include transmission of sound in the ear, transduction of sound and head orientation by hair cells, biophysics and biochemistry of hair cells, representation of sound and balance in eighth-nerve discharge patterns, anatomy of the central auditory and vestibular systems, and synaptic transmission and signal processing in central neurons. Aspects of hearing and balance such as speech perception, sound localization, vestibular reflexes and vestibular compensation are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data. Prerequisites: 580.421-422 or equivalent. Recommended: 110.302 Differential Equations, 520.214 Signals and Systems.

Hearing Science Center Staff 3 hours
fall/even years, spring/odd years

580.628 Topics in Systems Neuroscience

This course consists of weekly discussions of current literature in systems neuroscience. The selected readings will focus on neural mechanisms for perception, attention, motor behavior, learning, and memory, as studied using physiological, psychophysical, computational, and imaging techniques. Students are expected to give presentations and participate in discussions. Prerequisite:

580.421-422 Physiological Foundations or equivalent.
Wang, Shadmehr 1 hour fall

580.630 Theoretical Neuroscience

Theoretical methods for analyzing information encoding and functional representations in neural systems. Models of single and multiple neural spike trains based on stochastic processes and information theory; detection and estimation of behaviorally relevant parameters from spike trains; system theoretic methods for analyzing sensory receptive fields; network models of neural systems. Both theoretical methods and the properties of specific wellstudied neural systems will be discussed. Prerequisites: Introduction to Neuroscience (580.422 or equivalent), Probability (550.420 or equivalent), and Signals and Systems (520.214).

Wang, Young 2 hours spring

580.631 Biomechanics and Motor Control

A quantitative approach to the study of the human motor system using tools from control theory and robotics. We use mathematics and simulations to learn how the brain controls movements of the limbs. Topics include dynamics of multi-joint limbs; dynamics of muscles and spinal control structures; kinematics and motion planning; time delays and predictive control; neural correlates of control in the brain; motor disorders; learning and adaptive control. Prerequisites: 110.302 Differential Equations, 110.201 Linear Algebra.

Shadmehr 3 hours fall

580.632 Ionic Channels in Excitable Membranes

See 580.425 for description. Advanced homework problems, paper presentations, and exam questions are added to the core curriculum.

Yue 3 hours fall/even years

580.634 Molecular and Cellular Systems Physiology Laboratory

Laboratory experience in cell imaging, motility, and excitation; stochastic simulation of ionic channel gating; expression and biophysical characterization of cloned and native ionic channels. Students work on one or two projects from this set, under faculty supervision.

Tung, Yue 3 hours fall/odd years

580.635 Project in Bioelectromagnetic Phenomena

Course project as a supplement to 580.435.

Tung 1 hour spring/odd years

580.636 Feedback Control in Biological Signaling Pathways

Signal transduction pathways in biological systems need to be precisely regulated. This control is done through feedback regulatory loops. Students in this course will formulate mathematical models of signaling pathways and analyze their behavior using engineering control theory. Prerequisites: 110.302 Differential Equations, 520.353 Control Theory.

Iglesias 3 hours fall

580.638 Cell Mechanics and Motility

Fundamental to their function, cells generate and respond to mechanical forces. For example, whole muscle cells contract, but all cells must move chromosomes during cell division. This class will cover macroscopic mechanics of cells and their cytoskeleton, physical models of force generation, and molecular models derived from recent atomic structures of force-generating proteins. Clinical effects, such as cardiomyopathies where these processes are defective, and new molecular measurement technologies will also be discussed. An interdisciplinary approach spanning molecular biology, biochemistry, physics, and engineering will be emphasized. Prerequisites: either 580.421 or 020.305-306.

Kuo 3 hours spring/odd years

580.639 Models of Physiological Processes in the Neuron

Graduate version of 580.439. Differs in that an advanced modeling project using data from the literature is required. Same prerequisites.

Young 3 hours fall

580.651 Introduction to Nonlinear Dynamics in Physiology

This course is designed for students who may be interested in applying the techniques of nonlinear dynamics and chaos to the analysis of physiological data. Topics covered will include fractals, strange attractors, bifurcations, state-space attractor reconstruction, Poincaré sections, dimension calculations, Lyapunov exponents, entropy, tests for determinism, nonlinear forecasting. Examples will be drawn from studies in cardiology, brain function, and the oculomotor system. Prerequisite: basic knowledge of signals and systems or permission of instructor.

Shelhamer 3 hours fall/even years

580.682 Computational Models of the Myocyte

The cardiac myocyte is one of the most extensively studied cells in biology. As such, it serves as a critically important example of how to develop quantitative, dynamic computational models of cell function. The graduatelevel course "Computational Models of the Cardiac Myocyte" will present a comprehensive review of all aspects of modeling of the cardiac myocyte. This includes a) experimental and theoretical approaches to the modeling of cardiac cell membrane ion channels and currents; b) models of voltage- and ion-dependent membrane transport systems, and cellular homeostatic mechanisms; c) intracellular calcium dynamics; d) force generation in cardiac myocytes; e) historical and modern integrative models of the cardiac myocyte; and f) models of disease processes in cardiac myocytes. The course will also cover emerging areas of modeling activity including a) mapping and modeling of signal transduction pathways in the cardiac myocyte; b) mechanisms by which such pathways modulate cell function. Prerequisites: Physiological Foundations of Biomedical Engineering or equivalent, differential equations or linear algebra/ differential equations, and a semester-long collegelevel course in a programming language such as C, C++ or Fortran.

Winslow 3 credits spring

580.684 Experimental Foundations for Neural Models

This course familiarizes students with the experimental tools that are used to provide the biological data base for neural models. Projects are designed to teach single unit recording in sensory nerve; characterization of complex receptive fields; cellular or synaptic potential measurement; evoked potential techniques; psychophysical measurement of sensory or motor function. Prerequisites: an introductory course on the nervous system, permission of instructor.

Sachs, Staff 3 hours spring

580.702 Neuroengineering

This course includes review and discussions by faculty with expertise in various interdisciplinary topics in neuroscience (basic and clinical) and engineering. Students actively participate in literature review, discussions, presentations, and limited laboratory work. The course covers topics such as neuromodeling (ion channels, neurons, neural networks), signal processing (EEG, seizures, evoked potentials), functional stimulation (electric and magnetic), neural prosthesis (neuromuscular disorders, cortical recording, prosthetic devices), imaging brain functions (infrared, PET).

Thakor 3 hours spring

580.744 Pattern Theory: From Representation to Inference

This course examines the metric pattern theory of Ulf Grenander in which shapes and patterns are studied as random processes on graphs. The course begins with the

study of Markov processes on directed acyclic graphs, including Markov chains and branching processes, and on random fields on regular lattices. Moving to the continuum, the course examines Gaussian random fields, second order representation theory and random processes of geometric shape through Gaussian fields on manifolds. Numerous examples are examined in image understanding and image analysis.

Miller 3 hours spring

580.801-802 Research in Biomedical Engineering

Staff credit varies

Case Western Reserve (1968)

Enrollment: Bachelors: 160, Masters: 60,
Ph.D.: 80. VIP: 20.

EBME 105. Introduction to Biomedical Engineering (3).

Biomedical engineering fields of activity. Research, development, and design for biomedical problems, diagnosis of disease, and therapeutic applications.

EBME 201. Physiology-Biophysics I (3).

Cell physiology. Electrophysiology of nerve and muscle. Motor system. Central nervous system. Sensory systems. Autonomic nervous system.

EBME 202. Physiology-Biophysics II (3).

Biological control systems. Cardiovascular, renal, respiratory, gastro-intestinal, and immune systems.

EBME 303. Structure of Biologic Materials (3).

Structure of proteins, nucleic acids, connective tissue and bone from molecular to microscopic levels. Principles and applications of instruments for imaging, identification, and measurement of biological materials. Prerequisite: EBME 201.

EBME 306. Introduction to Biomedical Materials (3).

Applications of biomaterials in different tissue and organ systems. Relationship between physical and chemical structure of materials and biological system response. Choosing, fabricating and modifying materials for specific biomedical applications. Prerequisite: EBME 201, EBME 202.

EBME 307. Prosthetic Systems (3).

Neuromuscular prosthetic systems. Functional electrical stimulation. Restoration of movement of paralyzed arms and legs. Design of implantable systems. Regulatory and ethical considerations. Prerequisites: EBME 201, EBME 310.

EBME 308. Biomedical Signals and Systems (4).

Quantitative analysis of biomedical signals and physiological systems. Fourier and Laplace transforms. Frequency response of systems and circuits. A/D conversion, sampling, and discrete-time signal processing. Filter design. Laboratory and computational experiences with biomedical applications.

EBME 309. Modeling of Biomedical Systems (3).

Mathematical modeling and computer simulation with biomedical applications. Neuromuscular control of skeletal movement. Mass transport processes in blood dialysis. Analysis of cardiac electrical activity. Biomechanics of bone. Prerequisites: EBME 201, 202, EEAP 246

EBME 310. Principles of Biomedical Instrumentation. (3).

Physical, chemical and biological principles for biomedical measurements. Modular blocks and system integration. Sensors for displacement, force, pressure, flow, temperature, biopotentials, chemical composition of body fluids and biomaterial characterization. Patient safety. Prerequisites: EBME 201, EBME 202, EEAP 246.

EBME 311. Artificial Organs (3).

Engineering replacements of kidney, lung, heart, and other organ functions. Chemical, electrical, mechanical, materials, pathological and surgical aspects. Prerequisites: EBME 201, 202.

EBME 313. Biomedical Engineering Laboratory I (2).

Experiments for measurement, assist, replacement, or control of various biomedical systems. Prerequisite EBME 201, 202, EEAP 245. Corequisite: ENGL 398.

EBME 314. Biomedical Engineering Laboratory II (2).

Continuation of EBME 313. Prerequisite: EBME 201, 202, EEAP 246.

EBME 320. Medical Imaging Fundamentals (3).

Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Prerequisite: EBME 201, 202, 310.

EBME 324. Laboratory Computing in Biomedical Engineering (3).

Hardware and software aspects of computer systems for laboratory application. Analog and digital interfacing. Signal conditioning and sample requirements. Computer control of laboratory instruments and data acquisition. Biomedical applications. Prerequisites: EBME 201, 202, EEAP 246.

EBME 359. BME Computer Simulation Laboratory (1).

Corequisite: EBME 309.

EBME 360. BME Instrumentation Laboratory (1).

Corequisite: EBME 310.

EBME 380. Design for Biomedical Engineers (3).

Design of a clinically useful product with potential commercial value.

Graduate Courses:

EBME 402 - Muscles, Biomechanics, and Control of Movement (4)

Quantitative and qualitative descriptions of the action of muscles in relation to human movement. Introduction to rigid body dynamics and dynamics of multi-link systems using Newtonian and Lagrangian approaches. Muscle models, receptors and reflexes with application to control of multi-joint movement. Forward and inverse dynamics of multi-joint, muscle driven systems. Dissection, observation and recitation in the anatomy laboratory with supplemental lectures concentrating on kinesiology and muscle function.

EBME 403 - Biomedical Transducers (3)

Analysis and design of transducers: optical, photo-electric, electrochemical, electrical, mechanical, electromechanical, and thermoelectric. Applications to biomedical systems. Prerequisites: EBME 310.

EBME 405 - Materials for Prosthetics and Orthotics (3)

Fundamental concepts of metallic and ceramic materials. Wear, corrosion, and failure of implants. Properties of hard tissues and joints. Characterization of biomaterials. Biocompatibility of materials. Orthopaedic and dental applications. Prerequisite: EBME 306.

EBME 406 - Polymers in Medicine (3)

Plastic implants in the body. Chemical and physical characteristics of biomedical polymers. Implant requirements, host-implants reactions. Physiological and biomechanical basis for soft-tissue implants. Design of modified biomaterials. Prerequisite: Consent of instructor.

EBME 407 - Applied Neural Control (3)

Fundamental concepts related to electrical stimulation of the nervous system. Cable equation, currents in volume conductors, electrical models of axons, interaction between axons and electrical fields, tissue damage of electrical stimulation, electrochemistry of electrical stimulation, electrodes for electrical stimulation, applications to neuromuscular, sensory, and other physiological systems. Prerequisites: EBME 451.

EBME 408 - Tissue and Cell Engineering (3)

Tissue engineering approach for augmentation or replacement of compromised tissue function in nerve, microvessels, skin and cartilage. Integrative exploration of the use of three-dimensional polymeric scaffolds and drug delivery vehicles, and gene therapy and cellular engineering for functional repair of injured tissues.

Prerequisite: Consent of instructor.

EBME 409 - Systems and Signals in Biomedical Engineering (3)

Fourier series and transforms. Sampling and noise. Digital filtering. Dynamic systems. Initial-value problem. Laplace transform. System linearization. Frequency response analysis. Nonlinear systems and maps. Numerical methods. Distributed systems. Application to biomedical problems. Prerequisite: ESYS 212.

EBME 410 - Medical Imaging Fundamentals (3)

Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Prerequisite: EBME 310, 409.

EBME 411 - Artificial Organs (3)

Engineering for replacement or augmentation of tissues (e.g., nerve or vascular) and organs (e.g., kidney and heart). Chemical, electrical, mechanical, materials, pathological and surgical aspects. Prerequisites: EBME 451 and EBME 452.

EBME 412 - Biomedical Signal Processing (3)

Application of digital processing techniques to biomedical signals. Spectra and digital filters. Processing evoked responses. Electrocardiograms, electroencephalograms, and other biomedical applications. Prerequisite: EBME 409.

EBME 414 - Laboratory Computing in Biomedical Engineering (3)

Hardware and software aspects of computer systems for laboratory application. Analog and digital interfacing. Signal conditioning and sample requirements. Computer control of laboratory instruments and data acquisition. Biomedical applications. Prerequisites: consent of instructor.

EBME 418 - Electronics for Biomedical Engineering (3)

Review of electronic circuits. Analog design for biomedical electronics. Low noise, precision amplification, shielding, grounding, interfacing, and electrical safety. Electrophysiological amplifiers and biomagnetic field measurements. Prerequisite: EEAP 246.

EBME 431 - Physics of Imaging (3)

Magnetic resonance imaging including Bloch equations, relaxation times, chemical shifts. Reconstruction techniques including 2-D Fourier transforms. Biomedical applications. Prerequisite: Consent of instructor.

EBME 451 - Physiological Processes I (3)

Cell and molecular biology. Nerve and muscle function. Motor systems and feedback control. Autonomic system mechanisms. Brain and sensory systems. Prerequisite: Consent of instructor.

EBME 452 - Physiological Processes II (3)

Heart and vascular system. Respiratory, renal, and regulatory systems. Gastro-intestinal system and metabolism. Prerequisite: Consent of instructor.

EBME 460 - NMR Spectroscopy and Imaging (3)

Fundamental and advanced topics in understanding and application of NMR imaging and spectroscopy. Theoretical description and specific examples of spin Hamiltonians, pulse sequences, and basic instrumentation. Prerequisite: Consent of instructor.

EBME 461 - Biomed Image Processing and Analysis (3)

Principles of image processing and analysis with applications to biomedical images from the nano-scale to 3D whole organ imaging. Topics include image filtering, enhancement, restoration, registration, morphological processing and segmentation. Prerequisite: EBME 308

EBME 478 - Computational Neuroscience (3)

Computational properties of nervous system. Modeling and simulation of neurobiological systems. Neuronal development, plasticity, and learning. Neural circuits. Neuronal dynamics. Brain systems. Neural networks. Prerequisite: Consent of instructor.

EBME 501 - Bioelectric Phenomena (3)

Models of excitable cells and membranes. Cardiac action potentials and propagation of excitation. Bioelectric sources, volume conductor fields, and inverse problems. Prerequisite: EBME 451.

EBME 502 - Cardiac Excitation, Rhythm, and Control (3)

Cardiac excitation: sub-cellular, cellular, and inter-cellular. Propagation of the cardiac electrical potential. Arrhythmias. Neural control of the heart. Vagal nerve stimulation. Neurotransmitters and neuropeptides. Prerequisite: EBME 501.

EBME 504 - Transport Processes of Biomedical Systems (3)

Mass and heat transport processes. Metabolic processes. Spatially lumped and distributed models of organs, tissues and cells. Numerical methods for computer simulation. Applications to cells, tissues, and organs. Prerequisite: Consent of instructor.

EBME 507 - Motor System Neuroprosthesis (3)

Design and implementation of neuroprostheses. Transformation of muscle action into limb movement. Musculoskeletal modeling and simulation. Control of the musculoskeletal system by neural stimulation. Prerequisite: Consent of instructor.

EBME 513 - Biomedical Optical Diagnostics (3)

Engineering design principles of optical instrumentation for medical diagnostics. Elastic and inelastic light scattering theory and biomedical applications. Confocal and multiphoton microscopy. Light propagation and optical tomographic imaging in biological tissues. Design of minimally invasive spectroscopic diagnostics. Prerequisite: EBME 403 or consent of instructor.

EBME 519 - Parameter Estimation for Biomedical Systems (3)

Linear and nonlinear parameter estimation of static and dynamic models. Identifiability and parameter sensitivity analysis. Statistical and optimization methods. Design of optimal experiments. Applications to cells, tissues, and organs. Prerequisite: Consent of instructor.

EBME 523 - Chemical & Optical Sensors (3)

Fundamental electrical, electrochemical, and optical measurement techniques. Sensitive and selective biological membranes based on ion, enzyme, and immuno-reactions. Sensor stability and response time. Prerequisite: EBME 403.

EBME 528 - Histopathological Analysis (3)

Histopathological Analysis Concepts, mechanisms and techniques of histopathology including cellular ultrastructure tissue characteristics, identification and analysis of disease, and quantitative microscopy. Tissues studied include heart, arteries, lung, brain, liver, kidney, and skin. Laboratory experience in preparation and examination tissues with emphasis on quantitative analysis. Correlation of histological samples with medical images