Biomedical engineering syllabus

Biomedical engineering examinations

Group A - Compulsory examinations (six required)

20-Bio-A1 Biomaterials and Biocompatibility

Structure and properties of amorphous solids. Physical and chemical bases for properties exhibited by materials. Polymeric biomaterials. Metallic biomaterials. Ceramic biomaterials. Composite materials. Material properties including mechanical, electrical, magnetic and thermal behavior; estimation of these properties through experimental means. Applications of biomaterials in tissue and organ systems. Relationship between physical and chemical structure of materials and biological system response. Selection, fabrication and modification of materials for specific biomedical applications. Biomaterials processing. Biomaterials degradation. Implant requirements. Host-implants reactions including wound healing response and inflammatory response. Physiological and biomechanical basis for soft-tissue implants. Design of modified biomaterials. Bulk and surface characterization of materials. Regulatory (e.g. FDA/CE processes), ethical, and standards (e.g. ISO & ASTM) considerations for the implementation and commercialisation of biomaterials and medical devices.

Textbooks (most recent edition is recommended):

- Ratner, Buddy DS., Allan S. Hoffman, Frederick J. Schoen and Jack E. Lemons editors, Biomaterials Science: An Introduction to Materials in Medicine, Academic Press, NY.
- J Temenoff & A Mikos, Biomaterials The Intersection of Biology and Materials Science, Pearson.
- William Callister, Materials Science and Engineering: An Introduction, Wiley.
- Joon Park and R S Lakes, Biomaterials, Springer.
- Michael M. Domach, Introduction to Biomedical Engineering, Pearson Prentice Hall.
- Askeland and Wright, The Science and Engineering of Materials, Cengage Learning.

20-Bio-A2 Process Dynamics and Control

Linear models of physical systems and processes, the concept of the transfer function. The transient response of linear systems to step, ramp and sinusoidal inputs. Bode plots and the frequency response analysis of systems. On-off, proportional, integral, derivative and combined control actions. Stability analysis of closed-loop systems. Feedback and feed-forward control. The state-space analysis of control systems. Modeling of nonlinear systems using the phase-plane and describing functions methods, stability of control systems involving nonlinear elements, the concept of limit cycles. A basic knowledge of sampled-data control systems including the z transform. The design of simple digital controllers. Application of the concepts of process dynamics and control to biological systems.

Textbooks (most recent edition is recommended):

- Coughanowr and Koppel, Process Systems Analysis and Control, McGraw Hill.
- Luyben, W.L., Process Modelling, Simulation and Control for Chemical Engineers, McGraw Hill, N.Y.
- K Ogata, Modern Control Engineering, Prentice Hall.
- Khoo, M., Physiological Control Systems: Analysis, Simulation, and Estimation, Wiley-IEEE Press.
- Seborg et al.’s, Process Dynamics and Control.

20-Bio-A3 Biomechanics

Biomechanics of 1. musculoskeletal, 2. cardiovascular, and 3. respiratory systems including general tissue characteristics, healthy systems function, and methods to measure these values. 1. Musculoskeletal system: characteristics and classification of tissues and joints, elastic and viscoelastic mechanical characterization of bone, cartilage, ligament and tendon; the stress-strain-time or constitutive equations for soft connective tissue components; basic kinematic and kinetic analysis of simplified cases. 2. Cardiovascular system:

properties of tissues that form the heart, and major-to-minor arteries and veins; mechanisms and characteristics of healthy heart and blood vessel function (rhythm, pressure patterns, blood return, etc.); stress-strain-time relationships in cardiac and vascular tissues. 3. Respiratory system: properties of the tissues that form sinuses-to-alveoli; mechanisms and characteristics of respiration (e.g. diaphragm induced pressure differential), oxygen diffusion through alveolar walls; stress-strain-time relationships in pulmonary tissues.

Textbooks (most recent edition is recommended):

- Nordin, Margareta and Victor H. Frankel, Basic Biomechanics of the Musculoskeletal System. Lippincott Williams&Wilkins.
- Edited by John Enderle, Joseph Bronzino, Introduction to biomedical engineering, Burlington, MA : Academic Press.
- Editors Hoskins, Peter R., Lawford, Patricia V., Doyle, Barry J. (Eds.), Cardiovascular Biomechanics.
- Editors Mary A. Farrell Epstein James R. Ligas, Respiratory Biomechanics: Engineering Analysis of Structure and Function.
- VC Mow and R Huiskes, Review of Basic Orthopaedic Biomechanics and Mechano-Biology, Philadelphia: Lippincott Williams & Wilkins. (ch. 1 à 7 & 12).
- Carol A. Oatis, Kinesiology: The Mechanics & Pathomechanics Of Human Movement, Philadelphia: Lippincott Williams & Wilkins. (Parts I, II (1,2), III (5), IV (6,7)).
- D. Bartel, D. Davy and T. Keaveny, Orthopaedic Biomechanics: Mechanics and design in Musculoskeletal Systems, Prentice Hall.

20-Bio-A4 Anatomy and Physiology

Description of the human systems. Skeletal system with anatomy of superior members, inferior members and rachis. Osteoarticular system: physiology of bones, osseous tissues, articular cartilage, tendons, ligaments and muscles. Respiratory system, circulatory system, digestive system, urinary system, nervous system, and reproductive system. Structure-function relationships in human body systems.

Textbooks (most recent edition is recommended):

- Guyton, AC and Hall, JE, Medical Physiology.
- Joseph Feher, Quantitative Human Physiology, Academic Press.
- Saladin Dr, Kenneth S, Anatomy and Physiology

20-Bio-A5 Systems Analysis & Control (16-Mec-A3)

Open-loop and feedback control. Laws governing mechanical, electrical, fluid, and thermal control components. Mathematical models of mechanical, hydraulic, pneumatic, electrical and control devices. Block diagrams, transfer functions, response of servomechanisms to typical input signals (step function, impulse, harmonic), frequency response, Bode diagram, stability analysis, and stability criteria.

Improvement of system response by introduction of simple elements in the control circuit. Regulation of physical process: proportional, integral, and derivative control. Theory of linear controller design.

Textbooks (most recent edition is recommended):

- Bissell, C.C., Control Engineering, Taylor & Francis.
- Gene F. Franklin, Feedback Control of Dynamic Systems.
- Michael C. K. Khoo, Physiological Control Systems: Analysis, Simulation, and Estimation.

20-Bio-A6 Biomedical Signal Processing

Analysis of continuous-time signals: impulse response and convolution; Fourier series and Fourier transform; magnitude, phase, and power spectra. Analysis of discrete-time signals: Nyquist sampling theorem; the Z-transform. Analog filters: standard prototypes, transformations, passive and active implementation. Design of finite impulse response (FIR) and infinite impulse response (IIR) filters. Generation and nature of bioelectric potentials including membrane and action potentials; electrodes and other transducers. Characteristics and

processing of common biomedical signals including the electromyogram (EMG), the electrocardiogram (ECG), and the electroencephalogram (EEG).

Textbooks (most recent edition is recommended):

- R. M. Rangayyan, Biomedical Signal Analysis, Wiley.
- Lathi, B.P., Signal Processing and Linear Systems. Oxford University Press.
- Haykin, Simon & Barry Van Veen, Signals and Systems, Interactive Solutions Edition, John Wiley & Sons Canada Ltd.
- John Semmlow, Circuits, Signals and Systems for Bioengineers
- Suresh R. Devasahayam, Signals and Systems in Biomedical Engineering

20-Bio-A7 Bioinstrumentation

Principles of design and analysis of electric instrumentation for biological applications. Ideal and non-ideal operational amplifiers, signal conditioning filters, sampling theory, analog to digital and digital to analog converters, sample and hold circuitry and multichannel data acquisition including the constraints imposed by real-time processing. The acquisition and processing of diagnostic signals such as the electrocardiogram, the echocardiogram, the blood pressure and hemoglobin oxygen saturation signals. Some basic knowledge of statistics for assessing the signal to noise characteristics of measured data. Safety standards in the clinical setting for electrical and electronic equipment in both non-invasive and invasive applications including applicable regulatory authorities and legal standards. Risk assessment and management. Quality management systems (QMS) and documentation protocols.

Textbooks (most recent edition is recommended):

- Webster, J.G. (Editor), Bioinstrumentation. Wiley.
- Webster, J.G. (Editor), Medical Instrumentation: Application and Design, Wiley.
- Biomedical Device Technology: Principles And Design 1st Edition, by Anthony Chan

Group B - Optional examinations (three required)

20-Bio-B1 Biochemical Separations

The fundamentals of downstream separation and purification processes such as membrane separation processes, protein separation and purification and other separation processes of economic importance to the fermentation industry. Cell Disruption. Solid Liquid Separation, filtration, centrifugation. Membrane separation. Isoelectric focussing. Adsorption. Chromatography principles, Crystallization.

Textbooks (most recent edition is recommended):

- E. Goldberg, Handbook of Downstream Processing.
- Blanch, H.W., D.S. Clark and Marcel Dekker, Biochemical Engineering.
- Shuler, M.L. and F. Kargi, Biochemical Engineering Basic Concepts. Prentice Hall.

20-Bio-B2 Biotransport Phenomena

Momentum, heat and mass transfer. Mass, linear momentum and energy balances. Differential analysis of laminar viscous flow. Differential analysis of heat conduction. Differential analysis of diffusion and convective transport. Biological examples of transport phenomena including: pharmacology and pharmacokinetics; absorption distribution, biotransformation, elimination, calculation of dosages; variability in drug response and adverse drug responses; drug delivery; microenvironment, transport and binding of small and large molecules; movement of cancer and immune cells; metastatic process, radiotherapy, chemotherapy, immunotherapy, hyperthermia, and photodynamic therapy of solid tumors. Numerical methods for computer simulation.

Textbooks (most recent edition is recommended):

- Bird, Stewart and Lightfoot, Transport Phenomena.

- George A. Truskey et al.'s, Transport Phenomena in Biological Systems.

20-Bio-B3 Cell and Tissue Engineering

Integration of relevant aspects of physiology, pathology, developmental biology, disease treatment and biomaterials to regenerative medicine in complex organ systems. Host response to tissue engineered constructs including complement, coagulation, immunological responses. Engineered replacements of kidney, lung, vascular, skin. Chemical, electrical, mechanical, materials, pathological and surgical aspects of construct development. 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. Cell selection.

Textbooks (most recent edition is recommended):

- Lanza, R.P., R. Langer and W.L. Chick (eds), Principles of Tissue Engineering, Academic Press.
- Berhard O. Palsson, Sangeeta N. Bhatia, Tissue Engineering, Pearson Prentice Hall, New Jersey.

20-Bio-B4 Robotics (16-Mec-B12)

Robot components (sensors, actuators, and end effectors, and their selection criteria); basic categories of robots (serial and parallel manipulators, mobile robots); mobility/constraint analysis; workspace analysis; rigid body kinematics (homogeneous transformation, angle and axis of rotation, Euler angles, cylindrical and spherical coordinates); manipulator kinematics and motion trajectories (displacement and velocity analyses, differential relations, Jacobian matrix); non-redundant and redundant sensing/actuation of manipulators; manipulator statics (force and stiffness); singularities; and manipulator dynamics.

Textbooks (most recent edition is recommended):

- Paul, R.P., Robot Manipulators - Mathematics, Programming and Control, MIT Press.
- Craig, J.J., Introduction to Robotics: Mechanism and Control, Addison-Wesley Publishing Co

20-Bio-B5 Rehabilitation Engineering

Introduction to rehabilitation engineering; Wheeled mobility: W/C history, technology and standards, fundamentals of manual W/Cs propulsion biomechanics, powered W/Cs and control systems; Functional disabilities: types of neuromuscular impairments; Specialized seating: classification of seating technologies, biomechanical principles of seating support & pressure, CAD/CAM seating applications; Hearing aids and cochlear implants: sensory and hearing aided technologies; Alternative & Augmentative Communication: rational, technologies & access strategies, principles of access & communication optimization; Prosthetics and orthotics: engineering principles of lower limb prostheses; ADL Devices: rational, design principles and use for upper & lower limb dysfunction; Measurement tools in rehabilitation engineering.

Textbooks (most recent edition is recommended):

- Rory A Cooper, Hisaichi Ohnabe, Douglas A. Hobson, An Introduction to Rehabilitation Engineering, CRC Press, Taylor and Francis
- Emily C. Bouck, Assistive Technology, Michigan State University

20-Bio-B6 Analytical Biochemistry

Relevant analytical techniques for characterization of biological systems and materials. Nuclear magnetic resonance. Fourier transform infra red analysis. SDS-PAGE and Western blotting. HPLC. Flow cytometry. DNA gel extraction and ligation. Plasmid DNA mini-preps and PCR. Affinity purification and electrophoresis. Surface analysis techniques including x-ray photoelectron spectroscopy, atomic force microscopy, interfacial tension and ellipsometry.

Textbooks (most recent edition is recommended):

- Mikkelsen, Susan R. and Eduardo Corton, Bioanalytical chemistry, Wiley Interscience.

- Holme, D.J. and H. Peck, Analytical Biochemistry, Longman.

20-Bio-B7 Ergonomics (17-Ind-B5 Ergonomics)

Basic human abilities and characteristics, including vision and hearing. Psychomotor characteristics. Anthropometry: static and dynamic human body dimensions and muscle strength. Environmental factors, including illumination, atmospheric conditions, noise, and vibration. Ergonomic work design, including layout of equipment, manual work aids, design of seating, and person-machine interfaces: instruments, controls, and software. Regulated standards for work, safety and schedules.

Textbooks (most recent edition is recommended):

- RS Bridger, Introduction to Human Factors and Ergonomics.
- Kodak Ergonomics Group, Ergonomic Design for People at Work, Volumes I and II. Van Nostrand Reinhold Co. Ltd.

20-Bio-B8 Applied Optics/Photonics

Basic optics of rays; reflection, refraction, and polarization. Lens systems and image formation. Principles of basic optical instruments such as magnifiers, microscopes and telescopes. Basics of light sources: lasers, light emitting diodes, thermal light sources, fluorescence, and photodetectors. Tissue optics and light-tissue interactions and dosimetry. Principles of fibre optics and light guides, endoscopic systems and applications. Biomedical applications of photonics such as phototherapy and photodiagnosis, tissue oximetry, optical spectroscopy and microscopy, fluorescence marking, microarray technologies, flow cytometry.

Textbooks (most recent edition is recommended):

- Prasad, N., Introduction to Biophotonics, Wiley.

20-Bio-B9 Medical Imaging

Image quality analysis criteria. Image filtering in the spatial and frequency domains. Image restoration: regularization filters, deconvolution filters, optimal filtering. Segmentation of medical images: thresholding techniques, segmentation into regions, pattern recognition. Registration of medical images. X-ray radiography: sources and their characteristics, spectrum, interaction with tissue, instrumentation, image formation and characteristics. Computed tomography: CT instrumentation, image formation, line itegrals, backprojection, projection-slice theorem, fan-beam reconstruction. Nuclear medecine: general principles, radiotracers, gamma camera, image characteristics, SPECT. Positron emission tomography: general principles, instrumentation, tracers, image formation. Ultrasound imaging: ultrasound wave propagation, tissue properties, transducers and properties, modes, clinical applications. Magnetic resonance imaging: nuclear magnetism, classic description, spin-spin relaxation, spin-echo sequences, imaging and signal encoding, instrumentation, excitation sequences, functional imaging.

Textbooks (most recent edition is recommended):

- Prince & Links, Medical Imaging Signals & Systems, Pearson Prentice Hall.
- Suetens, P., Fundamentals of Medical Imaging, Cambridge University Press.

20-Bio-B10 Biomechanical Device Design & Human Factors

Introduction, terminology and classification of biomedical devices (primarily mechanical in nature) including implantable devices (joint prostheses, heart valve replacements, etc.), surgical devices/tools (i.e. non-permanent internal use), and external devices (e.g. orthoses, assistive devices, etc.). Assessing device usability through usability studies and clinical trials. Design History Files, QMS process (quality management system), Safety and Risk Assessment and Management: risk analysis; planned use; identification of dangerous physical and biological phenomena; assessment of the probability and severity of damage; control of risks; follow-up of incidents/post-deployment surveillance. Laws, regulations and standards (e.g. development and verification). Quantitative assessment and conditions of clinical trials.

Textbooks (most recent edition is recommended):

- Paul G. Yock, Biodesign: The Process of Innovating Medical Technologies.
- Jonathan S. Kahan, Medical Device Development: Regulation and Law.
- Paul H. King, Richard C. Fries and Arthur T. Johnson, Design of Biomedical Devices and Systems.
- Shurr and Michael, Prosthetics and Orthoses.

20-Bio-B11 Orthopaedic and Injury Biomechanics

Introduction to chronic diseases and acute injuries effecting the musculoskeletal system, and methods to treat these conditions. Conditions to be addressed include osteoarthritis, bone fracture/healing, muscular injuries (chronic/acute), ligament/tendon injuries, traumatic head injuries. Analysis of existing and design of novel devices/methods for treating the above conditions including partial/total joint replacements (i.e. arthroplasty), internal fracture fixation (e.g. plates/rods, screws, etc.), biologics/biomaterials for muscle/tendon healing, tools for surgical treatment, devices to prevent brain injury (e.g. helmets/restraint systems). Testing methods for assessing disease/injury conditions and treatment methods.

Textbooks (most recent edition is recommended):

- Nordin, Margareta and Victor H. Frankel, Basic Biomechanics of the Musculoskeletal System, Lippincott Williams & Wilkins.
- D. Bartel, D. Davy and T. Keaveny, Orthopaedic Biomechanics: Mechanics and design in Musculoskeletal Systems, Prentice Hall.
- Schmitt, K.-U., Niederer, P.F., Cronin, D.S., Morrison III, B., Muser, M.H., Walz, F., Trauma Biomechanics: An Introduction to Injury Biomechanics.
- Beth A. Winkelstein, Orthopaedic Biomechanics

20-Bio-B12 Advanced Control Systems (16-Elec-B2)

Modelling of engineering systems; state variables and transfer function representations. Analytical and numerical solutions of state variable equations. Observability, controllability, stability; classical design, stabilization by pole assignment. Systems with noise. Computer control, discrete systems. System identification; least squares.

Textbooks (most recent edition is recommended):

- Dutton, Ken, Steve Thompson, and Bill Barraclough, The Art of Control Engineering, Prentice Hall.
- Nise, Norman, John Wiley, Control Systems Engineering.

20-Bio-B13 Advanced Electronics (16-Elec-B5)

Device models: circuit behaviour, high frequency, and feedback. Multi-stage amplifiers, oscillators, current mode op-amps, non-linear circuits. Power amplifiers and linear regulators. Instrumentation: differential amps, optical isolators, and analog-digital and digital-analog converters.

Textbooks (most recent edition is recommended):

- Sedra and Smith, Microelectronic Circuits, Oxford University Press.
- Horowitz, Paul, and Winfield Hill, The Art of Electronics, Cambridge University Press

20-Bio-B14 Cellular Physiology and Biophysics

Chemical and physical structure of proteins, enzymes, nucleic acids, connective tissue and bone from molecular to microscopic levels. Relationship of chemical and physical structure of proteins to function including regulation of enzyme activity. Rate processes in biology. Systems of differential equations and stability analysis. Gene networks and signal transduction pathways. Enzyme kinetics, inhibition and cooperativity. Diffusion and mass transport in biological systems. Facilitated transport across membranes. Co-transport, counter-transport, ion pumps. Diffusion of macromolecules and random walks. Structure of

cellular membranes, Singer-Nicholson fluid mosaic model. Membrane potentials, Gibbs-Donnan equilibrium potentials. Protein-protein and protein-DNA interactions, receptor –ligand interactions, cell adhesion, cell migration, signal transduction, cell growth and differentiation.

Textbooks (most recent edition is recommended):

- Rodney Cotterill, Biophysics: An Introduction.
- Andrey Rubin, Fundamentals of Biophysics.
- Rob Phillips, Jane Kondev, Julie Theriot and Hernan Garcia, Physical Biology of the Cell.

20-Bio-B15 Fundamentals of Microbial Kinetics

Recombinant DNA technology, including cloning, directed mutagenesis, DNA sequencing and expression of cloned genes. Genomic engineering techniques. Basic principles of bioprocessing fundamentals, which includes: kinetics of enzymatic reactions and microbial growth, batch and continuous cell growth kinetics, products formation and nutrient utilization, bioreactor systems. Basic principles of biochemical engineering. Applied enzyme catalysis, immobilized enzyme technology, kinetics of substrate utilization, product formation and biomass production in cell culture, batch and continuous culture. Applications of biochemical engineering. Transport phenomena in biochemical engineering systems, design and analysis of bioreactors, mixing, aeration, sterilization, instrumentation and control in bioprocesses. Internal and external mass transfer in immobilized systems. Oxygen mass transfer parameters of a bioreactor and design of an aeration system. Scale up of Bioprocesses. Development and use of recombinant proteins as therapeutic drugs.

Textbooks (most recent edition is recommended):

- Blanch, H.W., D.S. Clark and Marcel Dekker, Biochemical Engineering.
- Bailey, J.E. and E.F. Ollis, Biochemical Engineering Fundamentals. McGraw Hill.
- Aiba, S., A.E. Humphrey and N.F. Mills, Biochemical Engineering, Academic Press.
- Shuler, M.L. and F. Kargi, De Lisa, Bioprocessing Engineering Basic Concepts, Prentice Hall.