Imperial College London

Department of Bioengineering

Undergraduate Syllabuses_2005–06

This publication refers to the session 2005–06. The information given, including that relating to the availability of courses, is that current at the time of going to press, October 2005, and is subject to alteration.

For details of **postgraduate** opportunities go to www.imperial.ac.uk/pgprospectus.

Bioengineering

Bioengineering is developing rapidly both nationally and internationally and its progress is reflected in changes occurring at Imperial College London. Since 2002, the Department of Bioengineering has offered an undergraduate degree course in Biomedical Engineering. This is in addition to the one-year MSc course in Engineering and Physical Sciences in Medicine which has been offered to about 30 students per year since 1991. The Department also provides MPhil/PhD training for which there are currently about 45 students.

The Department is active in many areas of research including biomedical sensors, mathematical modelling of biological and physiological processes, theoretical and experimental neuroscience, medical imaging, exercise biomechanics, microbionics and bio-inspired circuit design, surgical planning, mechanical approaches to the aetiology, diagnosis and management of cardiovascular, respiratory and musculoskeletal diseases, software for healthcare, and the analysis and interpretation of biomedical data.

The staff of the Department are drawn from fields ranging from mathematics, the physical sciences and engineering to the biological sciences and medicine. Much of the research undertaken is collaborative; with other departments at Imperial, with medical colleagues from hospitals associated with the College, and externally with colleagues from around the world. The Department was awarded a 5* (the highest possible rating) in the last appraisal of British universities by the government.

Undergraduate courses

Biomedical Engineering degree students may take a three-year course (BH81) leading to the BEng degree or a four-year course (BH9C) leading to the MEng degree. Both courses have a common first two years and a common final year. MEng students will spend the additional year taking more specialist engineering courses which are usually concentrated in one of the traditional engineering disciplines, usually Electrical Engineering or Mechanical Engineering. Final decisions about whether to take the three or four-year course can be delayed until the end of the second year.

The first two years include fundamental training in mathematics, engineering and medical science including material on bioengineering techniques and design. The final year includes courses on applied biomedical engineering topics and a research project.

Students admitted to the courses must satisfy the general University entrance requirements and those specific for the course. Students must normally have A2 level passes in mathematics and physics, plus an additional A2 level subject or two AS level subjects with high grades (AAB or above). A knowledge of chemistry and/or biology is useful but not essential. Competence in English must be proven.

The course consists of lectures supported by study groups and tutorials with additional practical classes and design projects in many of the modules.

Syllabuses

FIRST YEAR

BE 101 Molecules, cells and diseases
BE 102 Mathematics I
BE 103 Foundations for engineering I
BE 104 Computing I
BE 105 Medical science I
BE 106 Electrical engineering
BE 107 Solid and fluid mechanics
BE 108 Heat and mass transport
BE 109 Introduction to biomedical engineering

BE 101 Molecules, cells and diseases

DR A. ALLEN, PROFESSOR M.J. LEVER, DR M. BOUTELLE
Introduction to cells: cells and organelles, macromolecules in cells, cell membranes, infectious agents, blood and blood cells.
Nucleic acids and gene expression: nucleic acids and chromosomes, DNA replication, the cell cycle and mitosis, gene organisation and transcription, protein translation and translational modification, analysis of DNA.
Metabolism: introduction to protein structure, energetics and enzymes, metabolic pathways and ATP production, mitochondria and oxidative phosphorylation, lipids and membranes, cholesterol, membrane trafficking, integration of metabolism.
Genetics: meiosis and Mendelian inheritance, DNA mutations and genetic diseases.
Cellular organisation of tissues: epithelial cells, epithelial tissues, extracellular matrix, connective tissues, fluid compartments of the body, nerve and muscle, signalling between cells.
Microbiology: nature of infection, bacteria, fungal pathogens and parasites, viruses, body defence to infection and use of vaccination.
Immunology: host defence overview, immune cells and organs, innate immunity, B-lymphocytes, T-lymphocytes, adaptive immune response. Introduction to cellular pathology.

BE 102 Mathematics I

DR D. BUCK, PROFESSOR J.R. CASH
Analysis: functions of one variable: exponential, logarithmic, and trigonometric functions—odd, even, inverse functions. Limits—continuous and discontinuous functions.
Differentiation: implicit and logarithmic differentiation; Leibniz's formula; stationary points and points of inflection; curve sketching; polar coordinates. Taylor's and Maclaurin's series; l'Hôpital's rule. Convergence of power series; ratio test; radius of convergence.
Complex numbers: the complex plane; polar representation; de Moivre's theorem; ln z and exp z.
Hyperbolic functions: inverse functions; series expansions; relations between hyperbolic and trigonometric functions.
Integration: definite and indefinite integrals; the fundamental theorem; improper integrals; integration by substitution and by parts; partial fractions; applications.
Linear algebra: vector algebra: basic rules; Cartesian coordinates; scalar and vector products; application to geometry; equations of lines and planes; triple products; linear dependence. Matrix algebra: double suffix notation; basic rules; transpose, symmetric, diagonal, unit, triangular, inverse and orthogonal matrices. Determinants: basic properties; Cramer's rule. Linear algebraic equations: consistency; elementary row operations; linear dependence; Gauss-Jordan method; Gaussian elimination; LU factorisation. Eigenvalues, and eigenvectors; diagonalisation.
Ordinary differential equations: first order equations: separable, homogeneous, exact and linear. Second order linear equations with constant coefficients.
Fourier series: standard formulae; even and odd functions; half range series; complex form. Parseval's theorem. Differentiation and integration of series.

BE 103 Foundations for engineering I

DR E. DRAKAKIS, DR E. BURDET, MR M. HOLLOWAY, DR S. SCHULTZ, PROFESSOR M.J. LEVER
Autumn and spring terms.
Mathematical introduction: basic functions and their plotting; differentials and derivatives; first order ODEs; basic vector algebra; complex number basics; dimensional analysis;.
Vibrations and waves: simple and damped harmonic motion: SHM of mechanical and electrical oscillators; damped oscillation, light, critical and heavy damping, Q value; superposition of two SHMs—Lissajou's figures. Forced oscillations: steady state, variation of displacement and velocity with the frequency of the driving force; resonance, bandwidth, transients. Transverse wave motion: waves on a string, wave equation, travelling waves; characteristic impedance and phase velocity; reflection and transmission at boundaries; group velocity; dispersion; waves in periodic structures. Waves on transmission lines: circuit model, phase velocity, impedance, group velocity; lossy lines, dispersion, impedance matching, reflection at mismatches.

Electromagnetics: electrostatics—force between point charges, electric field, flux, flux density, Gauss' law, electrostatic potential, capacitance, energy of an electrostatic system; magnetostatics—magnetic field, force on current carrying conductor, magnetic flux density, Biot-Savart law, magnetic field intensity, permeability, Ampere's circuital law, inductance, energy in a static magnetic field, mutual inductance, coupling coefficient; motion of charged particles within electric and magnetic fields, mass-spectrometer basics.
Atomic physics: introduction to atomic, molecular and nuclear structure; Bohr theory, radiative transitions, introduction to atomic spectra. Quantum theory; black body radiation, Planck's constant, photoelectric effect, Compton scattering. Wave-particle duality, de Broglie's hypothesis. Schrödinger's equation.
Semiconductor physics: semiconductors—conductors, insulators, semi-conductors; crystal structure of group IV materials; donor and acceptor impurities; band structure; effective mass—holes and electrons; density of states, Fermi-Dirac probability function, hole and electron densities. Mobility, conductivity, Hall coefficient. Introduction to semiconductor devices—p-n junction, bipolar junction transistor (BJT), metal-oxide-semiconductor-field-effect-transistor (MOSFET); low-frequency equivalent cicruits.
Geometric optics: rays, Fermat's principle, the laws of geometrical optics; reflection and refraction of paraxial rays by spherical surfaces; image formation properties of thin lenses; optical instruments—the microscope.

BE 104 Computing I

DR P.M.M. CASHMAN
Introduction to digital electronics: gates, truth tables, Boolean algebra, Karnaugh maps, binary number representations, combinational arithmetic circuits. Flip-flops, counters and registers; binary multiplication. Monostables, multiplexers and memories; ROM, EPROM, RAM. Examples of medical applications.
Data representations: octal, hex, BCD, ASCII.
Computer architecture: 6800 CPU function, CPU registers, internal bus, memory organisation. Instructions, fetch/decode/execute cycle.
Assembly programming: mnemonics, directives, labels, jumps, loops, register functions, addressing modes, ALU instructions, stack operations, subroutine call and return, parameter passing, peripheral interface adapter (PIA) programming, polled I/O and interrupts.
Peripheral devices: digital-to-analogue and analogue-to-digital converters. Programmable timers, DMA controllers, disk drives, serial data transmission and RS-232. Microcomputers and software: evolution of the Macintosh and the IBM PC, the 68000 and 80x86 processors, RISC and SPARC architectures, e.g. PIC-16 processor. Operating system structure and function, file organisation, introduction to UNIX.
Introduction to programming: comparison between programming languages. ANSI C variables, types and expressions; assignment statements; input and output; control statements; using variables, I/O and loops; constants; input/output streams; interaction of C with UNIX and DOS shells; functions and variable scope; function arguments and the stack; recursive functions. Arrays; null-terminated character strings; multidimensional arrays, array initialisation. Pointers; string library functions; type conversion and casting; structures and unions; dynamic memory allocation; linked lists; stacks, queues, binary data trees. Command line processing; file handling; preview of object-oriented data handling.
Program design: bottom-up and top-down strategies, defensive design, pseudo-code, testing, debugging and documentation.

BE 105 Medical science I

DR M. RAMPLING, MR P. ENEVER, DR P.D. WEINBERG, PROFESSOR M.J. LEVER
*General anatomy and body system*s
Bone: structure and properties, joints; Control of body processes.
The nervous system: cells of the nervous system, transmission of information, the genesis of the resting potential, action potential generation and conduction, neurotransmitters, organisation of the nervous system, blood supply to the nervous system, peripheral nervous system, autonomic nervous system, learning and memory.
The cardiovascular system: heart anatomy, chambers, valves, conduction system, coronary circulation,

heart development and fetal circulation, mechanical properties of the heart, blood vessels and blood flow, microcirculation, electrical activity of the heart, CVS regulation, the electrocardiogram, response of the CVS to exercise and stress, arrhythmias, atherosclerosis, haemorrhage, haemostasis and thrombosis.
The respiratory system: lung cell biology, gas transport and ventilation, structure and function of the airways, lung mechanics, control of breathing.

BE 106 Electrical engineering I

PROFESSOR R.A. SPENCE, DR S. SCHULTZ
The circuit design process. Kirchhoff's laws: component relations.
Linear circuits equivalence.
Systematic analysis: nodal analysis, superposition. Thévenin's theorem, Norton equivalent circuit, controlled sources voltage controlled sources, analysis of circuits containing VCCSs.
Non-linearity: load-line analysis. Small-signal circuit analysis: small-signal models of components. Operational amplifiers: the ideal op-amp. Inverting circuit. Digital to analogue converter, non-inverting signal. Input offset voltage/current. Slew rate. Frequency response, gain bandwidth trade-off. Voltage follower. V-I converters. Log/antilog amplifiers. Large-signal behaviour. Compatator and analogue-digital converter.
AC circuits: reactive components—the inductor, the capacitor. Sinusoidal sources. Phase and magnitude relations. Use of complex notation, complex voltages and currents; equivalent KCL, KVL and component relations; algebraic notation and phasor representation; AC circuit analysis.
Small signals: small signal analysis principles; derivation of equivalent KCL, KVL and component models.

BE 107 Solid and fluid mechanics I

PROFESSOR K.H. PARKER, DR A.M.B. BULL, DR S. SHEFELBINE
The relationship between mechanics and applied mathematics. Dimensional analysis. Newton's second law. Statics. Particle dynamics. Linear momentum, energy and work. Dynamics of a system of particles. Rotational momentum, energy and work. Continuum mechanics. Rigid body mechanics. Examples in biomechanics.

BE 108 Heat and mass transport processes II

PROFESSOR R.C. SCHROTER, DR D. O'HARE
Thermodynamics: basic definitions—temperature, heat, work, energy; system and control volume approaches.
First law: enthalpy, heat capacity, phase changes.
Second law: entropy, free energy, reversible and irreversible processes, equilibrium, chemical potential. Third law: Maxwell's relations; equations of state; introduction to statistical mechanics; thermal conductivity. Introduction to the concept of the three basic transport processes— momentum, heat and mass transfer.
Conduction—steady state: Fourier law; conduction through a single slab; heat flow across composite walls; composite plane wall with heat transfer to fluids on each side; concepts of a heat transfer coefficient, overall heat transfer coefficient and resistance; contact resistances; heat transfer across cylinders and spheres; concept of fins and lagging.
Conduction—transient: step change in temperature at surface of a solid. Control volumes and surfaces. Idea of lumped and distributed parameters.
Dimensional analysis: units and fundamental dimensions; dimensional homogeneity and consistency of units; dimensionless groups.
Convection—introduction to convection: underlying fluid mechanics; concept of boundary layers; Newton's law of cooling.
Convection—forced convection: laminar and turbulent flow over flat plates and cylinders.
Heat exchangers: counter-current, co-current and cross flow systems.
Convection—free convection: vertical flat plate, horizontal cylinder and sphere.
Radiation: concept of a black body; Stefan-Boltzmann law; radiation between black body and surroundings; grey body; emissivity, absorptivity, reflectivity and Kirchoff's law; real bodies.

BE 109 Topics in biomedical engineering

DEPARTMENT OF BIOENGINEERING STAFF
A course of lectures, practical exercises and design projects designed to explore some principles and applications in biomedical engineering.

SECOND YEAR

BE 202	Mathematics II
BE 203	Foundations for engineering II
BE 204	Computing II
BE 205	Medical science II
BE 206	Electrical engineering II
BE 207	Solid and fluid mechanics II
BE 208	Heat and mass transport II
BE 209	Signal and systems
BE 210/ BE211	Humanities or management studies

BE 202 Mathematics II

PROFESSOR J. STARK, PROFESSOR Y. CHEN
Partial differentiation: functions of more than one variable—partial differentiation; total differentials, changes of variable; Taylor's theorem for a function of two variables; stationary values; contours.
Vector calculus: parameterised curves; scalar and vector fields; grad, div and curl; arc length; line integrals; conservative fields; double and triple integrals; Jacobians; Green's theorem in the plane; surface integration; Gauss' and Stokes' theorems. Partial differential equations; classification; wave equation; characteristics. Diffusion equation; similarity solutions. Laplace's equation. Separation of variables.
Complex variables: analyticity, differentiability in a region, Cauchy-Riemann equations, Laplace's equation. Simple mappings, multivaried functions. Conformal mappings. Cauchy's theorem and the residue theorem. Evaluation of complex and improper integrals including poles on the real axis.
Transforms: Fourier transforms; definition, inverse and properties. Fourier convolution theorem. Application to the solutions of PDEs.
Laplace transforms: definition, inverse and properties. Laplace convolution theorem. Use in solving ODEs.

BE 203 Foundations for engineering II

PROFESSOR M.J. LEVER, DR R. DICKINSON, DR M. BOUTELLE
Physics of atoms and molecules: molecular structure; bonding, valency. Atomic and molecular spectra. Nuclear magnetic resonance, electron spin resonance. X-rays; sources and interactions. Elementary particles and their interactions with matter.
Electromagnetic waves: differential forms; for electrostatics, the divergence of an electrostatic field; Laplace's and Poisson's equations; for magnetostatics; the curl of a vector field. Vector magnetic potential. Continuity of charge and concept of displacement current. Maxwell's equations in differential form. The Helmholtz equation; plane waves, phase velocity, polarisation, impedance, power flow, Poynting's theorem. Boundary conditions; reflection and refraction of plane waves from conductors and dielectrics at plane and oblique incidence, total reflection, Bewster angle. Waveguides; conducting boundaries; dielectric waveguides; optical fibres.
Masers and Lasers; stimulated emission, Einstein coefficients, population inversion, gain.
Physical optics: Huygen's construction; diffraction, Gaussian beams, resolution limits, resonant cavities. Coherent optics; transform properties of lenses, Abbé theory of the microscope, phase contrast microscopy. Optical signal processing; holography, synthetic aperture radar, beam steering.

BE 204 Computing II

DR P.M.M. CASHMAN
Review of structs and pointers; dynamic memory allocation; linked lists; self-ordering lists; binary trees; sorting algorithms; hash tables. Command line processing; file handling; use of header-specified data types in files; implementation of simple data objects and database applications in C. Review of software engineering principles, design, testing and debugging procedures. Software engineering concepts: data representations; requirements capture; the unified modelling language (UML). Data abstraction and encapsulation. The C++ class and data member access permissions; function and operator overloading, polymorphism and inheritance. Message passing; cin and cout streams. Constructors and destructors. Formal problem specifications via UML.

BE 205 Medical science II

DR D. CHAPPEL, PROFESSOR M.J. LEVER, DR P.D. WEINBERG
Introduction to endocrinology: anterior pituitary, posterior pituitary, thyroid, islets of Langerhans and their disorders, male and female gonads, adrenals and their hormones, endocrine control of calcium.
Spinal cord function and dysfunction: development of the CNS, brainstem and cranial nerves, thalamus and hypothalamus, the touch sensation, nociception, two-point discrimination, motor cortex, basal ganglia.
Introduction to gastrointestinal physiology: oesophagus, stomach and duodenum; normal anatomy and physiology, gastritis and peptic ulcers, pancreas, anatomy and histology, neutralisation of acids, synthesis and secretion of enzymes, liver: anatomy, histology and function, biliary system, small intestine: functional anatomy and physiology, malabsorption.
The kidney and urinary system: structural basis of kidney function, renal blood flow and glomerular filtration, tubular function, control of water excretion, control of sodium excretion, control of potassium excretion, mechanisms of acid-base balance.
Musculoskeletal system: the molecules of movement, muscles working together, force and movement.
Reproductive system: pregnancy and birth.
Skin: structure of the skin, ageing, functions of the skin, control of body temperature.

BE 206 Integrated devices and circuits

DR E.M. DRAKAKIS, DR J. NG, DR A.A. BHARATH
Integrated technology: historic milestones; lithography; passive components; BJT technology; MOSFET technology; BiCMOS technology; state of the art; state of the art.
The BJT: deviations from ideality; T- and π-equivalents; HF small-signal model.
The MOSFET: deviations from ideality; π equivalent; HF small-signal model; noise sources
Basic IC building blocks: current-mirrors; voltage-references (VT and bandgap); current-references. Single-stage amplifiers. Common-gate; common-base; common-source; common-emitter.
Cascade of single stage amplifiers (audio-range) AC coupling; DC coupling. HF response, design examples for biopotentials.
BJT differential-pair: large-signal behaviour; CMRR, slew, emphasis put upon its OTA amplifier role.
MOS differential-pair: large-signal behaviour; CMRR, slew, emphasis put upon its OTA amplifier role.
An introduction to information theory: modulation—AM, FM and phase modulation. Applications in bioengineering.
Digital communication: the bit, entropy, Shannon's source coding theory, Huffman coding, arithmetic coding.
Probability theory: random variables. Distributions, density functions, bivariate statistics, conditional statistics and density functions. Inference Bayes' theorem, contingency tables.
Learning: unsupervised learning, k-means algorithm, supervised learning, the single neuron, Bayesian networks.

BE 207 Solid and fluid mechanics II

PROFESSOR K.H. PARKER, DR A.M.B. BULL
Spring and autumn terms.
Fluids: Eulerian mechanics and control volumes. Dimensional analysis applied to fluid mechanics. The conservation of mass and momentum. Hydrostatics. Reynolds transport equations. Inviscid flow, the

Bernoulli equation. Viscous flow, Poiseuille flow. Rotating flows. Turbines. Unsteady flows, Stokes flow, Womersley flow. Turbulence. The differential equations of flow.
Solids practicals: the presentation of data, scientific report writing, log books, stress concentration lab, Young's modulus lab.
Solids lectures and design project: definition of the problem (each year a new problem—the design of a new orthopaedic device).
Selection and use of engineering materials: strength, toughness, stiffness, fatigue, creep, temperature resistance, wear, corrosion resistance.
Biomaterials: basic concepts, materials used in orthopaedics.
Fracture fixation devices: materials, design features, bone properties.
Practical orthopaedic imaging: MRI, CT, X-ray, nuclear imaging.
Revision of statically determinate force systems: force/moment equilibrium. Statically indeterminate systems: beams, cylinders welding, joining, adhesives.
Commercial issues: CE mark/FDA.

BE 208 Heat and mass transport II

PROFESSOR R.C. SCHROTER, DR D. O'HARE
Introduction to irreversible thermodynamics: equilibrium, dynamic and steady state conditions. Transport: kinetic theory of matter, Brownian motion, diffusion, Einstein equation, Fick's first law for steady state transport, chemical potential, partial pressures of gases in solution, Fick's second law for non-steady transport: concentration as a function of position and time, diffusion with reaction, rate processes, control volumes and areas. Simultaneous heat and mass transfer, humidification, radiation. Mass and energy transport in multi-component systems, membranes, permeability, restricted diffusion, osmosis, flow through porous materials, reflection coefficients. Convective and diffusive transport, Peclet number, concentration polarisation, ultrafiltration, mass transport boundary layers. Axial and radial (Taylor) dispersion, convective mixing—effects of secondary flows, eddies, turbulence, etc.

BE 209 Signals, systems and control

DR A.A. BHARATH, DR E. BURDET
Control Systems: Introduction and concepts; Applications of feedback control and stability analysis: Open vs. Closed loop systems; Stability issues; Routh table. Time domain analysis: Impulse and step responses; Design of controllers; Laplace domain analysis: Root-Locus Method; Bode plots; Nyquist Stability Criterion.
Analogue signals and systems: signal types—analogue signals, discrete-time signals, amplitude quantised, discrete-time signals, point processes; deterministic signals vs stochastic signals.
Simple signal operations: amplitude scalings, temporal shifts, dilation and contraction.
Measures on signals: temporal average, signal norms, 1,2 infinite. Similarity measures: inner products, normed inner products; families of inner products; correlation.
Examples: application to finding temporal patterns in biomedical data.
The Fourier transform: introduction as a family of inner products, Fourier transform properties, applications, and inverse. Parseval's theorem. Graphical representation via magnitude and phase spectra.
Generalised functions, periodic signals: Fourier series.
The sampling theorem: Nyquist rate, signal reconstruction, interpolation.
Systems: definition, classification.
Examples of systems: linear, non-linear; time varying, time invariant; open-loop, closed-loop.
LTI systems: properties, representation of LTI systems. Impulse response and Fourier domain transfer function. Filtering. Ideal filters, Filter approximations.
Filter applications: medical signal processing and imaging, noise removal, signal shaping, signal enhancement, signal deconvolution.
Laplace transforms: limitations of Fourier theory, and the necessity of the LT. Comparison of LT and FT kernels. Properties of LT, region of existence, s-domain—⇢ Fourier domain, tabular inversion. Applications of Laplace transform: s-plane, stability, s-plane poles and zeros. Laplace-domain transfer function, stability of closed-loop systems, Bode plots.
Digital signal processing: discrete-time signal representation. The Kronecker delta. Elementary

operations: addition, multiplication, subtraction, inner product, convolution, correlation.
The z-transform: definition, properties, convolution equivalence theorem, inversion, rational polynomial form for z-transform expressions, graphical representation (pole-zero plots).
The discrete Fourier transform (DFT): definition, properties, the inverse discrete Fourier transform.
General applications: spectral analysis, filtering, image reconstruction.
Applications in biomedical signal analysis: spectral analysis—Doppler signal processing, brief reference to central slice theorem and reconstruction from projections, reference to *k*-space.
Discrete-time systems: types of system—linear, non-linear, causal/acausal, recursive/non-recursive. Linear, time-invariant discrete-time systems.
Digital filters: impulse response, *z*-domain transfer function and Fourier domain transfer function. Types—FIR/IIR, advantages and disadvantages of both.
Implementation: recursive/non-recursive filter implementation; lattice filters, and multi-rate filtering. Applications of digital filters: signal conditioning (de-noising).
Practicals: pattern recognition example (ECG peak detection), Doppler velocity estimation.

BE 210 Humanities

Subjects currently available are: Art of the twentieth century, Communicating science: the public and the media, Controversies and ethical dilemmas in science and technology, Creative writing, European history 1870–1989, Global history of twentieth-century things, History of medicine, Humanities essay, Music and western civilisation, Music technology, Modern literature and drama, Philosophy, Politics, Saying true things: how science invents and persuades, Science and technology in western civilisation, The Roman Empire, languages. See the Humanities syllabuses for details.

BE 211 Health economics

PROFESSOR N. BOSANQUET
Concepts and evidence for health and healthcare; the drama of choice with scarce resources; decision-making techniques in economics; CBA ,CEA and CUA. The measurement of disease burdens—QALY's and DALY's. Cases studies of decision-making in cancer screening, prevention and treatment. Case studies of prevention and treatment in CHD. Health systems—UK, Europe and US. Key variables and issues; diffusion of technology; economics of imaging; economics of ICT; impacts of new technology in key disease areas. Developing health services in Asia; scenarios of health service development.

THIRD OR FOURTH YEAR

BE 303	Image processing
BE 305	Medical imaging
BE 306	Physiological monitoring and data analysis
BE 310	Biomechanics
BE312	Advanced medical imaging
BE 315	Modelling of physiological and pathological processes
BE 3	Project
BENGP01	

BE 303 Image processing

DR A.A. BHARATH
Image perception: light, illumination model, reflectivity, transmissivity.
The mammalian visual system: rods, cones, visual pathways and receptive fields, visual cortex. Spatial tuning, the Mach band effect. Simple monochrome vision model. Spatio-temporal tuning. Colour: hue, brightness, saturation, tristimulus values. Colour spaces: RGB, CMY, YIQ, HIS. Image representation. Image features.
Digital images: representation, size issues. Discrete image models: facet model, bi-linear fitting. Stochastic models. Two-dimensional covariance function, WSS random fields, isotropy.
Binary image processing: definition, production, Bayesian optimal thresholding. Neighbourhood relationships, connectivity, distance measures. Structure representation: boundary extraction, chain codes, linking, run-length codes, signatures, quadtrees, moments, moment invariants, connected

component labelling, medial axis extraction.
Image transforms: applications—compression, segmentation, analysis—DCT, Haar, DFT, radon and Hough transforms, wavelet. Optimal transform matched to application. Separable transforms, inversion, computational issues.
Neighbourhood operators: relationship to image transforms, convolution, smoothing, Gaussian scale-space, enhancement, edge detection, filter banks, feature extraction.
Computational issues: separable vs non, border effects.
Non-linear operators: order statistic, mathematical morphology—binary erosion, dilation, opening, closing, noise removal, hole filling. Greyscale morphology, top hat and umbra transforms. Image segmentation: applications in medical imaging. Image domain and feature space approaches. Region growing, aggregation, splitting and merging. Feature spaces: notion, dimensionality, discriminant functions, and decision hypersurfaces. Nearest neighbours and minimum distance classifiers. Training sets.
Clustering: k-means algorithm, modified k-means, and ML clustering. Morphological clustering. Overfitting and computational issues. Dimensionality reduction, feature selection.
Edge detection: definition of an edge, gradient based, zero crossing-based. Gradient magnitude estimation and direction. Mask design, noise-free and noisy bi-linear facet model. Unbiased and minimum variance masks in gradient-based edge detection. Zero crossing via LoG. Multiscale operation. Direction estimation. Edge linking using direction information. Phase and Hessian based edge-detection.

BE 305 Medical imaging

DR I. DELAKIS, DR R. DICKINSON
X-ray imaging: nature of X-rays—E-M radiation. Interactions of high-speed electrons with matter. Generation of X-rays. Brehmsstrahlung radiation. X-ray spectrum. Characteristic X-rays. Interaction of X-rays with matter. Photoelectric effect. Compton scatter, absorption. Pair production, Rayleigh scattering. Empirical treatment of attenuation. Collision cross-section. Ideal Beer's law. Linear attenuation coefficient—components of LAC, variation with tissue density, variation with photon energy. Film—image formation physics, gamma characteristic, the ideal imaging system. Contrast with ideal Beer's law. Departures from ideal. Image mottle—quantum nature and secondary photons. Geometric blurring. Beam hardening. Image quality—broad image quality goals. Quantitative image quality measurements. Dosage. Risk considerations—exposure measurements. Genetic dose equivalent. Effective dose equivalent. Dosage/signal-to-noise trade-offs and dosage/contrast trade-offs—exposure times, beam energies. Dose and contrast/noise. Real X-ray imaging equipment. X-ray tube. Anode materials. Anode rotation. Heat dissipation/tolerance. Filters—necessity, materials and applications. Anti-scatter grid. Collimation. Film. Film/screen combinations. Trade-offs. Electronic detection. Contrast agents. Examples, clinical benefits and drawbacks. Safety. Standard radiological safety checks. Introduction to digital X-ray.
Basic principle of CT: scanning configurations and implementation, translate-rotate scanners—scatter-rejection, speed, artefact. Fan-based scanning, detector matching, artefact. Stationary detector systems, real time detector calibration. Spiral CT. Image quality—spatial resolution, density resolution, artefact. Point spread function, FWHM figure, MTF. Factors affecting spatial resolution—isotropy, aperture size and axial resolution, image spatial resolution—aperture size, reconstruction filter, number of views, contrast. Density resolution—ultimate limiting factors, scatter, voxel size, reconstruction error. Artefact—aliasing, streak and ring artefact, dependence on geometry, beam hardening artefact. Digital image manipulation: grey-level windowing, ROI selection, archiving, DICOM. Ultrasonic imaging—ultrasound waves, wave parameters, intensity. Propagation in tissue, impedance, attenuation. Transducers, materials, construction, half-wave resonance, quarter-wave matching, arrays. Ultrasound beams, near-field/far field, Fraunhofer diffraction. A-mode systems. Pulse generation. Envelope detection. TGC. Compression. B-mode imaging. Scanning geometries—rectilinear, curvilinear. Mechanical scanning. Linear array scanning. Phased array scanning, beam steering. Interpolation. B-mode processing. Position sensing, beam forming. scan conversion. Velocimetry: Doppler shift. Continuous wave Doppler. Signal demodulation. Quadrature demodulation. Audio Doppler signal. Frequency estimation. Pulsed Doppler. Range cell and resolution. Demodulation. Interpolation. Aliasing. Colour Doppler, colour mapping.
Magnetic resonance imaging: NMR phenomenon. Quantum and classical descriptions—dipole moments, spin quantum numbers, Zeeman energy levels, gyromagnetic ratio, spin populations, Larmor equation, angular momentum and torque—alternative Larmor derivation, macroscopic magnetisation. MR

hardware—types of magnet, advantages and disadvantages. Block diagram of MR system, field strengths, coils. Relaxation phenomena, Bloch equations, precession, T1 and T2, relation to tissue properties, free induction decay, spin dephasing, T2*. Basic pulse sequence—spin-echo, contrast mechanisms. Imaging—general considerations, gradients, slice selection, bandwidth, frequency and phase-encoding, FOV, matrix sizes, signal averaging, scan-time, multiple slices, *k*-space. Image artefacts—ghosting, ferrous and non-ferrous metallic, magnetic susceptibility, Gibbs ringing, aliasing.

BE 306 Physiological monitoring and data analysis

DR P.M.M. CASHMAN, DR M. BOUTELLE
ECG monitoring: origin and significance of the ECG signal, Einthoven standard leads, chest leads, electrode artefacts and interference, shock hazards, leakage paths, special hazards of personal computers, mandatory precautions, IEC601-1, isolation amplifiers. Epicardial and endocardial electrodes. Required frequency responses. ECG telemetry and data coding. Display and recording methods. QRS detectors, heart rate measurement, QRS morphology.
Applications: precordial mapping, intracardiac ECG, arrhythmias, Holter monitoring, ST segment monitoring, late potentials, HRV and spectral analysis. Cardiac pacemakers. Obstetric and fetal monitoring—the cardiotocograph, fetal HR measurement, uterine activity measurement, pulse oximetry, clinical and research applications. Pressure measurement—origin of the BP signal, catheter-transducer and tip systems, automatic indirect and ambulatory BP monitors, clinical and research applications of BP. Group design practical.

BE 310 Biomechanics

PROFESSOR R.C. SCHROTER, PROFESSOR K.H. PARKER, PROFESSOR M.J. LEVER, DR A.M.J. BULL
Properties of tissues: mechanical properties in relation to molecular structure.
The collagen family and their elastic properties: elastin, ageing; microfibrils: fibrillin, etc. Proteoglycan family. Deformation of soft tissues, non-linear elasticity, viscoelasticity—skin, measurement of stress and strain in tissues in two and three dimensions.
Bone: compact bone, organisation of trabeculae, ligaments and tendons, growth and remodelling, deformation of cartilage, lubrication; intervertebral disc.
Cell mechanics: membrane and cytoskeletal properties, deformability, adhesion.
Cardiovascular mechanics: pump characteristics of the heart; mechanical properties arteries, veins and capillaries, including changes on ageing and in disease; waves in the circulation, blood rheology; blood flow in arteries, veins. Network flow in the microcirculation, mass transport processes between flowing blood and tissues.
Respiratory mechanics: lung parenchymal and chest mechanics; airway dynamics.
Prostheses: matching of mechanical properties; adhesion; remodelling.
Musculoskeletal Mechanics: muscle mechanics, mechanics of joints, inverse dynamics: intersegmental force and moment analysis, muscle optimisation techniques.

BE 312 Advanced medical imaging

DR D. McROBBIE AND OTHERS
X-ray imaging: fluoroscopic/fluorographic imaging: image intensifiers, special techniques, DSA, interventional radiology.
Mammography: breast screening, risk vs benefit considerations.
Digital radiography: digital fluoroscopy. Fluorography, storage media, computed radiography, PACS.
Advanced image quality: MTF, evaluation of contrast/details thresholds, square wave and edge response functions, ROC analysis, figure of merit. Performance assessment: Quality assurance, test objects, phantoms. Radiation protection: risks and hazards, patient dose, occupational dose, shielding, room design, the critical examination, dose reduction measures, measurement of patient dose, dose surveys. Radiation protection legislation: guidance, codes of practice, basic safety standards, EU directives.
X-ray CT technology: continuous rotation systems, slip rings, detector systems, relationship between detector system and image quality, resolution enhancement techniques, flying focal spot, quarter wave shift, third and fourth generation trade-offs.
Image reconstruction from projections: algebraic interpretation, central slice theorem, convolution

backprojection, reconstruction filters, effect of filters on image quality, image reconstruction artefacts, spatial sampling and aliasing. Iterative reconstruction, ART and SIRT algorithms; ML reconstruction and EM algorithms. Spiral CT: pitch factor, interpolation, reconstruction, multiple slice systems. Quantitative and functional CT: dynamic CT, bone densitometry, CT angiography, CT fluoroscopy. CT image quality: noise, uniformity, slice width, spatial resolution, MTF, figure of merit, test objects, artefacts. CT dosimetry: dose profile, CTDI, practical measurement, patient dosimetry, scattered radiation, radiation protection issues, daily and monthly QA tests.
Ultrasonic Imaging: transducer design and construction: the piezoelectric effect, transducer construction and characteristics, crystal thickness and resonance, damping, matching layer. Focusing techniques: lens, curved elements, mirrors. Focal zone characteristics: DOF, PMI, focal area, far and near field characteristics. Transducer arrays: linear, linear phased, annular. Electro-acoustic modelling. U/S Field Theory: Beam Formation, lateral and axial resolution, beam steering, focusing and apodisation. Advanced Doppler techniques: spectral analysis, DFT, autocorrelation techniques. Colour haemodynamic systems. Velocity vector analysis and display, digital RF signal processing. Doppler signal quantification: empirical, curve fitting methods, mathematical methods, quantitative blood flow rate measurements, vessel compliance measurements. Therapeutic techniques: bioeffects, thermal interactions/cavitation, transducer array design, beam focusing, clinical studies: lithotripsy, ablation, hyperthermia, physiotherapy. Three-dimensional ultrasound: position sensing, image data acquisition, interpolation techniques, editing procedures, volume and surface rendering techniques, display modes, ultrasound tomography. Ultrasound RF analysis: radiofrequency signal data, signal analysis: bulk properties, structural organisation parameters. Systems architecture: equipment types, system design, QA protocols, Acoustic output measurements, preventative maintenance protocols, first line maintenance. Contrast Agents and Harmonic Imaging: Nature of contrast agents, areas of clinical application, fundamental and harmonic imaging, stimulated acoustic emissions, drug delivery. Dosimetry and Safety: Thermal, non-linear and cavitation effects. Cellular effects. Cooling mechanisms *in vivo*. Ultrasound field measurements, thermal and mechanical indices, operating parameters, International safety regulations.
Magnetic resonance imaging: NMR phenomenon. Reference frames, resonance and Bloch equations. MR hardware: magnet design and constraints, superconductivity, gradient coil design, gradient performance, eddy currents and shielding. Components of receiver chain: coil design, coil loading, quadrature and array coils, SNR vs field strength. Advanced pulse sequences: CPMG, stimulated echoes. Fast imaging sequences: k-space, segmented sequences, FLASH, turbo-FLASH, fast spin-echo, echo-planar, sequential scanning. Clinical scanning techniques: contrast agents, paramagnetic ions, positive and negative contrast agents, fat suppression, chemical shift, chemical and motion artefacts, gating, STIR, in and out-phase techniques, chemical selection, spatial saturation. MR Angiography: Physics of flow effects, in-flow, phase effects, gradient moment rephasing, time-of-flight MRA, phase-contrast MRA, two-dimensional and three-dimensional techniques, TONE, MIP, quantitative velocity measurement, Fourier encoding.
Advanced contrast mechanisms: BOLD effect, diffusion, perfusion, magnetisation transfer. MR Spectroscopy: chemical shift, common nuclei for investigation, spectral features, line widths, technical requirements, localisation methods, CSI. MR image quality: SNR and resolution, assessing image quality, test objects, parameters, test materials.
MR safety II: bioeffects and safety, biological effects of static, time-varying fields, magneto-hydrodynamic effect, neuromuscular stimulation, heating, SAR, exposure limits and units. Pacemakers, implants, standards, guidance and organisational issues, siting and environmental issues.

BE 315 Modelling of physiological and pathological processes

DR M. BARAHONA
General goal: The design and use of models of physiological and pathological processes in elucidating complex processes.
Topics: Introduction to dynamical processes: continuous and discrete; deterministic and stochastic. Use of analytical and computational techniques for the analysis of dynamics. Introduction to optimization.
Applications in Biology and Physiology to a selection of topics from among the following:
(a) *Modelling of neural function*: Hodgkin-Huxley and cable theory. Modelling with artificial neural networks. (b) Applications of non-linear dynamics concepts and algorithms. (c) *Control systems in the body*: Heart rate variability; Control of tissue and blood glucose. (d) *Mathematical and mechanical*

models of cardiovascular function: Network theory applied to the microcirculation. (e) *Biodynamics*: Models of stress and strain distribution in hard and soft tissues. (g) *Collective and network dynamics in biology and medicine*: Pharmacodynamics; Infection and immunity; Population dynamics.

MS 315 Biomaterials, artificial organs and tissue engineering

DEPARTMENT OF MATERIALS STAFF
Biomedical materials: orthopaedic alloys, orthopaedic ceramics, bioactive ceramics, resorbable biomaterials, soft tissue replacement materials, cardiovascular replacement materials.
Prosthetics and orthoses: lower limb prosthetics and upper limb orthotics. Computer-controlled functional stimulation. Robot technology. Studies of limb motion. Gait. Safety problems of excessive loads. Design criteria for implants; external orthotic devices; everyday aids for disabled people; functional stimulation.
Implanted prosthetics: joints, ligaments and tendons, long and short-term properties of artificial and bio-implants, biocompatibility, biomaterials including bioglasses, plastics, shape memory alloys.
Mechanical testing of tissues: material lifetime, wear and fatigue problems.
Artificial organs: extracorporeal circulations—pumps, filters, heat and gas exchangers. Dialysers
Tissue engineering: chemically modified tissues, xenografts. Need and concept; cell population of artificial or biopolymer matrices. Cell-cell and cell material bonding; adhesion molecules, matrix expression by cells. Collagen and other biopolymers, inflammatory and immunological reactions, genetic manipulation to limit tissue reactions, bioreactive materials. Osteoconductive materials, control of cell proliferation and differentiation, resorbable scaffolds, clinical applications and limitations.
Clinical engineering: advanced tools and training aids for the surgeon; robotics in surgery; career development for bioengineers. Regulatory issues, Ethical issues.

BE 320 Computational Neuroscience

DR M. BARAHONA, DR A.A. BHARATH, DR E. BURDET, DR H. KRAPP, DR S. SCHULTZ
Definition and Scope: Overview and history. *Systems* - visual information processing in the retina, thalamus and visual cortex. Visual perception. Hearing and the auditory system: from the cochlea through to auditory cortex. The somatosensory system: spinal cord, ventral posterior nucleus, somatosensory cortex, the sense of touch. Somatotopic maps. The motor system: spinal mechanisms, motor cortex and voluntary movement, the cerebellum. *Electrical properties of neurons*: the cell membrane, integrate-and-fire and conductance-based neuron models, spike rate adaptation, refractoriness. The Hodgkin & Huxley model. Axons & dendrites: the cable equation, multi-compartment neuron models. Synapses: synaptic physiology, synaptic models. *Neural network models*: Firing rate models. Feedforward networks: the perceptron, multilayer networks. Coordinate transformations. Recurrent networks: linear and nonlinear recurrent networks, the Hopfield network, associative memories. Adaptation and learning: supervised and unsupervised learning. Networks of integrate-and-fire neurons. *Spike train statistics*: the neural code, spike rate and spike timing codes. Receptive fields and sensory information processing. Reverse correlation and spike-triggered analysis methods; constructing simple and complex V1 receptive fields. Information theory and the neural code. Population coding. The neural code and perception: ROC analysis. Decoding neural spike trains. Invited research talks.

BE 3BENGP01 Project

DEPARTMENT OF BIOENGINEERING STAFF AND OTHERS
The third term is spent on an extended research project. Projects are available in many different areas. They are assessed by a written dissertation and an oral examination.