Faculty of Natural Sciences

IMPORTANT NOTES

If for one subject you can find several different types (lecture, practice, laboratory) of courses then please choose one and only one course from each type in order to be able to perform the subject's requirements successfully.Civil Engineering courses are on the website seperately. Courses chosen from the offer of Faculty of Civil Engineering will be checked and arranged individually by the departmental coordinator.

Subject code	Subject name	Requirement	ECTS credit
BMETE119779	MATLAB Programming	Mid-semester mark	3

Course type	Course code	Course language	Timetable information
Laboratory	E1	English	

MATLAB programming course (2020 / spring) Educator: Gabor Varga PhD, Associate Professor, Department of Physics, BUTE E-mail: vargag@phy.bme.hu Course frequency: 2-hour/week LAB work near the computer using MATLAB Semester duration: 14 weeks Semester requirement and mark: 90 minutes test at the end of semester: writing a MATLAB code for a given algorithm (100 point) and semester project (100 points) Marks: 0-79 failed (1), 80-109 poor (2), 110-139 average (3), 140-169 good (4), 170-200 excellent (5) Thematics: 1. MATLAB environment and programming: matrix operations, basics of linear algebra, rendering of one-, two- and three-dimensional functions, printing, file operation, control commands, graphical user interface (GUI). Basics of object-oriented programming. 2. MATLAB data types and operations: matrices, arrays, structure, cell, character, string, logical 3. Get skill in MATLAB programming by writing numerical algorithms of derivation, integral and ordinary differential equations. Debugging of MATLAB programs. 4. Program design and writing within the semester project: core of numerical solver, handling of file input/output, character and graphical based user interface. 5. Program testing. Validation of MATLAB code and simulation. Optimization of speed and memory. 6. Scientific style program documentation. Inserting help and demo in MATLAB code of semester project. 7. Short presentation of semester project.

Subject code	Subject name	Requirement	ECTS credit
BMETE11AF11	Applied Solid State Physics	Exam	2

Course type	Course code	Course language	Timetable information
Lecture	T0	English	THU:10:15-12:00

Band structure of metals and semiconductors, electron transport, electron scattering mechanisms, 2 dimensional electron gases, Si technology (FET, SSD memory), semiconductor heterostructure (semiconductor laser, MEMT), nanoelectronics, single electron transistor. – Magnetic materials, origin of magnetic momentum and interaction between moments, magnetic structures. Magnetism of metals, spin polarized bands, spintronics devices (spin valve, MRAM). Spin transistor, magnetic semiconductors.– Jenő Sólyom: Fundamentals of the Physics of Solids (Springer 2007) – Thomas Ihn: Semiconductor Nanostructures: Quantum States and Electronic (2009)

Subject code	Subject name	Requirement	ECTS credit
BMETE11AF38	Computer Controlled Measurements	Mid-semester mark	3

Course type	Course code	Course language	Timetable information
Laboratory	T1	English	MON:14:15-18:00(F3213)

The participants gain experience in computer controlled measurements and in the programming of scientific instruments and data acquisition system. To this end the following topics are covered: communication with the instruments via serial, GPIB, and USB ports. Programming of data acqusitin cards. Programming of complex measurement control platforms, plotting and saving the data, programming of timelines, in situ data analysis. The course consists of 4 hour long computer laboratory exercises every second week. In the first part of the semester fundamental programming skills are obtained through simple example programs. In the second part the participants individually program complex measurement control and data analysis platforms, like nonlinear curve fitting by Monte Carlo method, full computer control of a digital multimeter, digital oscilloscope program using a data acquisition card.

Subject code	Subject name	Requirement	ECTS credit
BMETE11AF51	Research Project	Mid-semester mark	3

Course type	Course code	Course language	Timetable information
Laboratory	T1	English	

During the semester, the student conducts research work under the guidance of a supervisor. The aim of the project is to get acquainted with the methodology of scientific research and to acquire professional knowledge beyond the curriculum. In order to complete the subject, the results of the independent work must be summarized in an essay of at least 20 pages, which cannot overlap with the diploma work. The results must be also presented in a lecture at the end of the semester. The dissertation and the presentation can be replaced by submitting a TDK dissertation at the

TDK conference.

Subject code	Subject name	Requirement	ECTS credit
BMETE11AX14	Nobel Prize Physics in Everyday Application	Exam	2

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	T0	English	TUE:14:15-16:00

Scope: The amazing and explosive development of technology is our everyday experience in various fields of life from informatics and medicine. It is less well known how this development is supported by scientific research. As an example a notebook computer applies numerous Nobel Prize awarded ideas, like the integrated circuits (2000), semiconducting laser (2000), liquid crystal display (1991), CCD camera (2009), GMR sensor of the hard disk (2007) and several further achievements from earlier days of quantum mechanics and solid state physics. The course is intended to give insight to a range of amazing everyday applications that are related to various Nobel Prizes with a special focus on recent achievements. The topics below are reviewed at a simplified level building on high school knowledge of physics. Syllabus:- Textbook applications from the early days of Nobel prizes: wireless broadcasting, X -rays, radioactivity, etc.- Optics in everyday application: lasers, CCD cameras, optical fibers, liquid crystal displays, holography- Quantum physics: from atom models to quantum communication- Measurements with utmost precision: application of Einstein's theory of relativity in GPS systems, atomic clocks, Michelson interferometry, etc.- Nuclear technology from power plants to medical and archeological applications- Advanced physics in medicine: magnetic resonance imaging, computer tomography and positron emission tomography- Semiconductors from the first transistor to mobile communication- Fundamental tools of nanotechnology (scanning probe microscopes, electron beam lithography, etc)- Spintronics from the discovery of electron spin to everyday application in data storage devices- Exotic states of solids in everyday application: superconducting magnets and levitated trains- Towards quot;all carbon electronicsquot;: envisioned and already realized applications of graphene

Subject code	Subject name	Requirement	ECTS credit
BMETE11AX22	Physics 2	Exam	4

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	VE0	English	TUE:12:15-14:00
Lecture	VN0	German	THU:10:15-12:00(F29)
Practice	VN1	German	TUE:14:15-16:00
Practice	VE1	English	TUE:14:15-16:00

Elektrodynamics: Faradayrsquo;s law. Self induction, mutual induction. Magnetic properties of materials. Magnetic data storage. Maxwell equations. Generation, propagation and reflection of electromagnetic waves. Basics of geometrical optics. Wave optics, interference, diffraction. Polarized light. Basics of atomic Physics: Natural and coherent light sources. Physical foundations of optical communication. Matter waves of de Broglie. The Schrouml;dinger equation. The electron structure of atoms. Electron spin. Free-electron theory of metals. Band structure of solids. Superconduction. Quantum-mechanical phenomena in modern electronics. Basics of nuclear physics. Nuclear reactors. Elementary particles. Curiosities in cosmology. Fundamentals of the physics of the atomic kernel, elementary particles, selected topics in cosmology.

Subject code	Subject name	Requirement	ECTS credit
BMETE11AX24	Physics 2i	Exam	4

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	IE0	English	TUE:12:15-14:00
Lecture	IN0	German	THU:10:15-12:00(F29)
Lecture	IT0	English	TUE:12:15-14:00
Practice	IN1	German	TUE:14:15-16:00(E406)
Practice	IE1	English	TUE:14:15-16:00
Practice	IT1	English	TUE:14:15-16:00

ELECTRIC FIELDS: Electric charges. Coulomb's law. Coulomb's constant and the dielectric constant. Electric field. Electric field of a point charge, a dipole, a group of charges, continuous charge distributions. Electric field lines. GAUSS' LAW: Electric flux. Gauss' law. Applications for charge distributions having a large degree of symmetry. Conductors in electrostatic equilibrium. ELECTRIC POTENTIAL: Potential energy associated with the electrostatic force. Electric potential difference (voltage) and electric potential. Equipotential surfaces. The electric potential of a point charge, a group of charges, a continuous charge distribution. Mathematical relationship between the electric field vector and the electric potential. Charged conductors in electrostatic equilibrium. CAPACITANCE AND DIELECTRICS: Capacitance. Parallel plate capacitor, cylindrical capacitor, spherical capacitor. Parallel and series combination of capacitors. Energy stored in a charged capacitor. The electric dipole in an external electric field: torque, potential energy. Dielectrics. Atomic dipole moments and the polarization vector. Electric susceptibility, relative dielectric constant. The electric displacement vector. Boundary conditions for the electric field vector and the displacement vector. Energy density of the electric field. CURRENT AND RESISTANCE, DIRECT CURRENT CIRCUITS: Electric current. Current density. Ohm's law. resistivity, conductivity, resistance. Power supplied by a battery. Power dissipated in a resistor. Parallel and series combination of resistors. Kirchhoff's rules. RC circuits:

charging and discharging a capacitor. MAGNETIC FIELDS. SOURCES OF THE MAGNETIC FIELD: Magnetism. Magnetic field. Magnetic force on a moving charge. Applications: cyclotron, velocity selector. Magnetic force on a current-carrying conductor. Torque on a current loop. The magnetic dipole. The magnetic field strength. The permeability of free space. Analogy between electricity and magnetism (electricity: acts on charges, is created by charges; magnetism: acts on moving charges, is created by moving charges). The Biot-Savart law and some of its applications. Magnetic force between two parallel conductors. The paradoxical nature of the force acting on a moving charge (resolution of the paradox using special relativity). Ampere's law. Applications for a long straight wire and a solenoid. The magnetic flux. Gauss' law in magnetism. The displacement current and the general form of Ampere's law. Magnetism in matter. The magnetization vector. Ferromagnetism, paramagnetism, diamagnetism. Boundary conditions for the magnetic field and the magnetic field strength. FARADAY'S LAW: Faraday's law of induction. Motional emf: a straight conductor moving through a perpendicular magnetic field; emf induced in a rotating bar. Lenz's law. Induced emf and the associated nonconservative electric field. Eddy currents. Maxwell's four equations in integral and differential form. Electromagnetic waves. INDUCTANCE: Self-induction. Self-inductance. RL circuits. Energy stored in an inductor. The energy density of the magnetic field. Mutual inductance. Oscillations in an LC circuit. The RLC series circuit. LIGHT AND OPTICS: Measurements of the speed of light (Roemer, Fizeau). Geometric optics, ray approximation. Reflection. Refraction and Snell's law. Total internal reflection. Huygens' principle. Fermat's principle. Dispersion. INTERFERENCE OF LIGHT WAVES: Spatial and temporal coherence. Young's double slit experiment, the intensity distribution on the screen. Phasor addition of waves. Generalization for N slits. Interference in thin films. Newton's rings. The Michelson interferometer. DIFFRACTION AND POLARIZATION: Fraunhofer diffraction on a single slit, the intensity distribution on the screen. Resolution of a single slit and a circular aperture. Rayleigh's criterion. Diffraction grating. The spectral resolving power of a grating. X-ray diffraction in crystals, the Laue condition. Fresnel zones. Zone plates and phase Fresnel lenses. Polarization of light waves: elliptical, linear, circular polarization. Polarization by selective absorption, reflection (Brewster's law), birefringence, scattering. Optical activity. LASERS AND HOLOGRAPHY: Interaction between light and matter: spontaneous emission, stimulated emission, absorption. Light amplification by population inversion. Resonators. 3-level and 4-level optical pumping. Electrical pumping. Laser types (solid-state, gas, liquid, semiconductor). Properties of laser beams. The basic idea of holography and its difference from conventional photography. Applications of holography. INTRODUCTION TO QUANTUM PHYSICS: Blackbody radiation and Planck's hypothesis. The photoelectric effect. The Compton scattering. Atomic spectra of low pressure gases. Bohr's quantum model of the hydrogen atom. QUANTUM MECHANICS: Wave properties of particles, de Broglie's hypothesis. The double slit experiment with massive particles. The wave function. The uncertainty principle. Particle in a 1D box. The Schrouml;dinger equation. Particle in a well of finite height. Tunneling and its applications. The simple harmonic oscillator.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF04	Seminar RP2	Mid-semester mark	2

Course type	**Course code**	**Course language**	**Timetable information**
Practice	T1	English	FRI:12:15-14:00(F3213)

In this seminar course, each student will process, and give a presentation about, a selected topic in modern physics. Knowledge of classical physics (mechanics, electromagnetism, thermodynamics, statistical physics) as well as basics of modern physics (quantum mechanics, quantum solid-state physics, special relativity) is essential.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF06	Seminar RP4	Signature	0

Course type	**Course code**	**Course language**	**Timetable information**
Practice	T1	English	FRI:12:15-14:00(F3213)

In this seminar course, each student will process, and give a presentation about, a selected topic in modern physics. Knowledge of classical physics (mechanics, electromagnetism, thermodynamics, statistical physics) as well as basics of modern physics (quantum mechanics, quantum solid-state physics, special relativity) is essential.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF07	Independent Laboratory RP1	Mid-semester mark	7

Course type	**Course code**	**Course language**	**Timetable information**
Laboratory	E1	English	

The student must have chosen a diploma work topic before registering to this course. The student performs research tasks related to the diploma work topic during the semester, under the guidance of the thesis advisor.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF12	Group Theory in Solid State Research	Exam	3

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	T0	English	THU:14:15-16:00

Introduction: point groups, fundamental theorems on finite groups, representations, character tables. Optical spectroscopy: selection rules, direct product representations, factor group. Electronic transitions: crystal field theory, SO(3) and SU(2) groups, correlation diagrams, crystal double groups. Symmetry of crystals: space groups, International Tables of Crystallography. Electronic states in solids: representations of space groups, compatibility rules.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF25	Seminar on Nanophysics 1	Mid-semester mark	2

Course type	**Course code**	**Course language**	**Timetable information**
Practice	T1	English	

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF33	Diploma Work RP	Mid-semester mark	30

Course type	**Course code**	**Course language**	**Timetable information**
Laboratory	E1	English	

The prerequisit to registering this course is successful completion of the course Independent laboratory RP2. The student performs research tasks related to the diploma work topic during the semester, under the guidance of the thesis advisor.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF42	Quantum Information Processing	Exam	3

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	T0	English	

Quantum bit, quantum computing, quantum algorithms. Spin-based quantum bits in solids: quantum dots, interactions, energy scales. Realization of single- and two-qubit quantum-logical operations. Mechanisms of information loss: relaxation, dephasing, decoherence. Experiments.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF48	Seminar NA2	Mid-semester mark	2

Course type	**Course code**	**Course language**	**Timetable information**
Practice	T1	English	

The students process a leading field of modern physics, and present their part to the others as a scientific talk.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF50	Seminar NA4	Signature	0

Course type	**Course code**	**Course language**	**Timetable information**
Practice	T1	English	

The students process a leading field of modern physics, and present their part to the others as a scientific talk.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF53	Fundamentals of Nanophysics	Exam	5

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	T0	English	WED:09:15-12:00

The building blocks of nowadays electronic devices have already reached a few tens on nanometers sizes, and further miniaturization requires the introduction of novel technologies. At such small length-scales the coherent behavior and the interaction of electrons, together with the atomic granularity of matter induce several striking phenomena, that are not observed at the macroscopic scale. The course gives an introduction to a broad set of nanoscale phenomena covering the following topics: characteristic length-scales; basic concepts of quantum transport, conductance quantization; coherent and incoherent transport, interference phenomena in nanostructures; mesoscopic phenomena in atomic and molecular nanojunctions; quantized Hall effect; noise phenomena in nanostructures; graphene nanostructures, 2D heterostructures; quantum dots.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF54	Optical Spectroscopy in Materials Science	Exam	5

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	T0	English	FRI:09:15-12:00

Electromagnetic waves in vacuum and in a medium; complex dielectric function, interfaces, reflection and transmission. Optical conduction in dipole approximation; linear response theory, Kramers-Kronig relation, sum rules. Simple optical models of metals and insulators; Drude model, Lorentz oscillator. Optical phonons, electron-phonon interaction. Optical spectroscopes: monochromatic- and Fourier transformation spectrometers. Optical spectroscopy of interacting electron systems: excitons, metal-insulator transition, superconductors. Magneto optics: methods and current applications.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MF57	Theory of Magnetism	Exam	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	THU:11:15-13:00
Practice	T1	English	THU:13:15-14:00

Magnetic phenomena are considered as electron correlation effects. This course builds heavily on knowledge gained by successful completion of the course “Modern solid state physics”. The following topics are discussed: Landau levels in magnetic field, magnetism of extended electron states, magnetism of atoms and ions, magnetite, direct exchange, kinetic exchange, Mott transition, Mott insulators, mean field theory of magnetic ordering, the ferromagnetic Heisenberg model, the antiferromegnetic Heisenberg model.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MX22	Physics Laboratory for Civil Engineers	Mid-semester mark	1

Course type	Course code	Course language	Timetable information
Laboratory	EA2	English	TUE:14:15-18:00(ONLINE); TUE:14:15-18:00(ONLINE)
Laboratory	EA1	English	WED:14:15-18:00(ONLINE); WED:14:15-18:00(ONLINE)

In the semester three measurements are to be performed: studying of standing waves on a stretched string; measuring specific heat, latent heat; measurements with thin lenses, prism, polarizers, and interferometer. The purpose is to get to know basic measurement techniques and simple equipment. The course is based on BSc physics knowledge.

Subject code	Subject name	Requirement	ECTS credit
BMETE11MX33	MSc Physics	Exam	4

Course type	Course code	Course language	Timetable information
Lecture	VE0	English	MON:10:15-12:00; MON:10:15-12:00; THU:10:15-12:00
Practice	VE1	English	THU:10:15-12:00

The course covers introduction to two disciplines: Quantum Mechanics and Solid State Physics. After the semester students should be able to understand the basic principles behind these two disciplines and solve some simple problems. This will contribute to the understanding of the workings of modern electronics and nanotechnology. Quantum mechanics: Experimental antecedents.The Wave function.Time dependent and time independent Schrouml;dinger's equation.Simple problems. Tunneling. Angular momentum. The hidrogen atom. Perturbations. Formal quantum mechanics. Operator calculus. Commutators, canonical conjugates and uncertainity relations. Harmonic oscillator. Selection rules and spectrum of H. The He atom, the independent particle approximation. The exclusion principle. Periodic system of elements. Molecules. molecular orbitals, chemical bonding, H-H bond. Molecules of many atoms. Orbital hybridisation. Conjugated molecules, cyclic conjugated molecules. Rotation and vibration of molecules. Franck-Condon principle, Rayleigh amp; Raman scattering. Classical and quantum statistics. Solid State Physics: The solid state. Short and long range order. Crystallography. Bonds in crystals. Real and point lattices. Symmetries and unit cells. The reciprocal lattice. Bravais lattices. X- ray diffraction methods. Electrical conductivity. Drudel model. Sommerfeld model. Band theory of solids.Work function. Contact potential. The adiabatic principle. Electrons in periodic lattices. Charge carrier characteristics. Crystal momentum. Effective mass. Band theory. The tight binding model. Intrinsic and doped semiconductors. Semiconductor structures. Superconductivity. Thermal properties. The transport equation. Onsager relations. Quantum theory of lattice vibrations. Optical properties. Magnetic and dielectric properties of solids.

Subject code	Subject name	Requirement	ECTS credit
BMETE12MF52	Selected Topics of the Modern Materials Science	Exam	3

Course type	Course code	Course language	Timetable information
Lecture	TE0	English	TUE:12:15-14:00

Subject code	Subject name	Requirement	ECTS credit
BMETE14MX00	Modern Physics for Chemical Engineers	Exam	3

Course type	Course code	Course language	Timetable information
Lecture	E0	English	MON:12:15-14:00; THU:10:15-12:00

Topics: The course covers introductions to two disciplines: Quantum Mechanics and Solid State Physics. After the semester students should be able to understand the basic principles behind these two disciplines and solve some simple quantum mechanical and solid state physics problems. This will contribute to the understanding of the workings of modern electronics and nanotechnology. To follow the course no higher mathematics than algebra and the basics of the differential and integral calculus is required. Detailed thematics: Quantum Mechanics. Blackbody radiation, photoelectric effect, Compton effect, stability and line spectra of atoms, Frank-Hertz experiment, Time dependent and independent Schrödinger's equation, stationary states, wave function, "wave - particle duality", electron diffraction, two-slit experiment, uncertainty relations, electron wavefunction probability distribution in an atom, solving the Schrödinger equation, tunneling, the ammonia molecule, electron emission from metals, perturbation calculus, selection rules, operator calculus, eigenstate problems, measurement, quantum mechanics of the hydrogen atom, quantum numbers, H spectrum and selection rules, electron spin, Zeeman-effect, Stern-Gerlach experiment, spin-orbit coupling, atoms with more than one electron, the exclusion principle, indistinguishable particles, periodic table of elements, buildup of shells, Hund's rule, valence and core electrons, molecules, molecular orbitals, chemical bonding, H-H bond, H2+ molecule ion, bonding and anti-bonding states, orbital hybridisation, heteronuclear molecules, sp3 hybridization, rotation and vibration of molecules, Franck-Condon principle, Rayleigh and Raman scattering, Stokes and anti-Stokes scattering, Statistical physics. Classical and quantum statistics. Distribution functions, distinguishable and indistinguishable particles, photon gas, Einstein model, laser principle. Solid State Physics. Short and long range ordering, amorphous and crystalline solids, crystal structures, lattices (point lattice and basis), symmetries and unit cells, primitive, conventional and Wigner-Seitz cells, primitive vectors, Miller indexes, Bravais lattices, close packing structures, reciprocal lattice, k-space, X-ray diffraction, Laue formulae, classical physical models for crystals: lattice vibrations, monatomic and diatomic linear chain model, boundary conditions, form of the solution, dispersion relation, generalization for 3 dim., QM handling of lattice vibrations, phonons, momentum and energy of phonons, relative to the momentum and energy of Bloch electrons, specific heat of solids, equipartition principle and the Debye model, specific heat from electrons, conductors and insulators, band theory of solids, formation of bands, insulators, conductors, real band structures, conduction models, Drude model, collision time, mean free path, Wiedmann-Franz law, Sommerfeld model of metals, Fermi energy, electrons and holes, equivalence of electron and hole conductivity in a completely filled band, metals with hole conduction, work function, thermionic emission, contact potential, crystal potential, double layer at the surface, Bloch functions, Hartree-Fock method, dispersion relation, Brillouin zone, reduced zone picture, kinematics of electrons and holes, Bloch oscillations, effective mass, tight binding model, semiconductors, intrinsic conductivity, density of states in the conduction and valence bands, position of the Fermi level, donors and acceptors, charge carrier concentrations, extrinsic conductivity, Fermi level in doped semiconductors, p-n junction, application of p-n junctions, diode, (MOS) FET, bipolar transistors, Schottky and ohmic structures, characteristics.

Subject code	Subject name	Requirement	ECTS credit
BMETE15AF32	Mechanics 2	Exam	2

Course type	Course code	Course language	Timetable information
Lecture	T0	English	MON:10:15-12:00

Relativistic mechanics: Lorentz-transformations, four-vectors and Minkowski space, relativistic collisions, relativistic action and equations of motion. Relativistic particle in an electromagnetic field. Lagrange-theory of continuum mechanics: Lagrange density of a string, Euler-Lagrange equations, energy density. Application to quantum mechanics and to harmonic media, Klein-Gordon equations. Hamiltonian formulation of continuum mechanics. Symmetries: Noether's theorem, symplectic formulation of Hamiltonian mechanics. Poisson's brackets, integrability. Canonical transformations, Hamilton-Jacobi equations, action-angle variables. Nonlinearity, second harmonic generation, parametric resonance. Basics of dynamical systems and chaos. – H. Goldstein: Classical Mechanics (Addison-Wesley)– J.R. Taylor, Classical Mechanics (University Science Books)

Subject code	Subject name	Requirement	ECTS credit
BMETE15AF34	Electrodynamics 2	Exam	2

Course type	Course code	Course language	Timetable information
Lecture	T0	English	MON:12:15-14:00(F3M01)

Electrostatics: Solving Laplace's equation in spherical and cylindrical coordinates. Grounded sphere in external field, electric field near a sharp cone. Multipole expansion in spherical harmonics. – Magnetic and quasistatic fields: magnetic scalar potential, solution methods in nonlinear materials. – Electromagnetic waves in vacuum and matter. Microscopic model for polarizability. Dispersion, plasma frequency, Kramers-Kroing relations. – Wave guides, resonant cavity. Losses, quality factor. – Radiation field of oscillating charges. Electric dipole and quadrupole, magnetic dipole radiations. – Scattering of electromagnetic waves, cross section. Scattering on solids and gases. – Lienard-Wiechert potential of moving charge, field strength, radiated power, angular distribution, spectrum. Synchrotron radiation. Cherenkov and transitional radiations. – Elements of relativistic electrodynamics. – David J. Griffiths: Introduction to Electrodynamics (Pearson)– John D. Jackson: Classical Electrodynamics (Wiley)

Subject code	Subject name	Requirement	ECTS credit
BMETE15AF42	Practical Course in Electrodynamics 2	Mid-semester mark	3

Course type	Course code	Course language	Timetable information
Practice	T1	English	WED:14:15-16:00

Problem solving class accompanying Electrodynamics 2. – David J. Griffiths: Introduction to Electrodynamics (Pearson)– John D. Jackson: Classical Electrodynamics (Wiley)

Subject code	Subject name	Requirement	ECTS credit
BMETE15AF44	Practical Course in Mechanics 2	Mid-semester mark	3

Course type	Course code	Course language	Timetable information
Practice	T1	English	TUE:12:15-14:00

Problem solving class accompanying Mechanics 2. – H. Goldstein: Classical Mechanics (Addison-Wesley)– J.R. Taylor, Classical Mechanics (University Science Books)

Subject code	Subject name	Requirement	ECTS credit
BMETE15AF46	Theory of Relativity	Exam	3

Course type	Course code	Course language	Timetable information
Lecture	T0	English	WED:10:15-12:00(F3M01)

Subject code	Subject name	Requirement	ECTS credit
BMETE15AF48	Electrodynamics 2	Mid-semester mark	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	MON:12:15-14:00

Electrostatics: Solving Laplace's equation in spherical and cylindrical coordinates. Grounded sphere in external field, electric field near a sharp cone. Multipole expansion in spherical harmonics. – Magnetic and quasistatic fields: magnetic scalar potential, solution methods in nonlinear materials. – Electromagnetic waves in vacuum and matter. Microscopic model for polarizability. Dispersion, plasma frequency, Kramers-Kroing relations. – Wave guides, resonant cavity. Losses, quality factor. – Radiation field of oscillating charges. Electric dipole and quadrupole, magnetic dipole radiations. – Scattering of electromagnetic waves, cross section. Scattering on solids and gases. – Lienard-Wiechert potential of moving charge, field strength, radiated power, angular distribution, spectrum. Synchrotron radiation. Cherenkov and transitional radiations. – Elements of relativistic electrodynamics. – David J. Griffiths: Introduction to Electrodynamics (Pearson)– John D. Jackson: Classical Electrodynamics (Wiley)

Subject code	Subject name	Requirement	ECTS credit
BMETE15MF21	Crystalline and Amorphous Material	Exam	3

Course type	Course code	Course language	Timetable information
Lecture	T0	English	

1. Introduction 1.1. Historical overview: Science and applications 1.2. Definitions Crystalline, non-crystalline, amorphous, glassy materials, 2. Preparation techniques 2.1. Growth of thin-film forms 2.2. Melt-quenched glasses 2.3. Other techniques 2.4. Phillips constraints theory 3. Structure 3.1. Differences between amorphous and crystalline semiconductors 3.2. Projection from three dimensional structures to one dimensional functions Diffraction measurements 3.2. Three dimensional structure derivation from one dimensional function 3.3. Atomic interactions. Computer simulation methods, Models 3.4. Phase change materials and its application 4. Electronic structure 4.1. Chemical bonds, 4.2. Electronic density of states, 4.3. Defects 4.4. Optical and electronic properties 5. Photo induced phenomena 5.1. Photoinduced volume changes (PVE), photodarkening, photobleaching (PD), 5.2. Photoinduced defect creation (PDC): the Staebler-Wronsky effect, 5.3. In-situ simultaneous measurements of PVE, PD, and PDC 5.4. Photoinduced amorphization or crystallization, 5.5. Some applications of photo-induced effects (solar cells, XEROX, sensors, DVD, etc.)

Subject code	Subject name	Requirement	ECTS credit
BMETE15MF63	Phase Transitions	Exam	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	
Practice	T1	English	

Subject code	Subject name	Requirement	ECTS credit
BMETE15MF65	Quantum Field Theory	Exam	7

Course type	Course code	Course language	Timetable information
Lecture	T0	English	
Practice	T1	English	

The course is a general introduction to relativistic quantum field theory.Canonical quantisation. Quantised Klein-Gordon and Dirac fields. Spin-statistics theorem.Interacting fields. CPT theorem. Scattering theory and the S-matrix. Unitarity and microcausality. Perturbation theory, Feynman rules for correlation functions.Asymptotic states. Feynman rules for the S matrix. Cross sections and decay rates.Quantisation of the electromagnetic field. Gauge invariance.Kallen-Lehmann representation, sum rules. LSZ reduction formulae.Feynman path integral in Hamiltonian and Lagrangian formalism.Functional formalism. Generator functionals. Free fields, Wick theorem.Grassmann variables and path integrals for fermions. Renormalisation theory. Classification of divergences, counter term formalism. Symmetries and Ward identities. Spontaneous symmetry breaking.Renormalisation group, Callan-Symanzik equation. Connection with theory of critical phenomena.M.E. Peskin and D.V. Schroeder: An Introduction to Quantum Field Theory (Addison-Wesley)C. Itzykson and J-B. Zuber: Quantum Field Theory (Dover Publications) S. Weinberg: The Quantum Theory of Fields I-III (Cambridge University Press)

Subject code	Subject name	Requirement	ECTS credit
BMETE15MF66	Theoretical Nanophysics	Exam	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	TUE:16:15-18:00
Practice	T1	English	TUE:18:15-19:00

Nanosystems and mesoscopic systems represent the most intensively studied areas of modern solid-state physics: modern lithographic procedures enable us to create semiconducting devices and metallic grains, where electrons move coherently. Today, we can contact individual grains, atoms and molecules, and place them into micro-resonators.The goal of the course is to cover novel phenomena occurring in such devices. I Knowledge of quantum mechanics solid-state physics and statistical physics is assumed. The course covers the following subjects: description of small grains (Coulomb interaction, coherence, single particle levels); fundamentals of random matrix theory (university classes, level repulsion); Coulomb blockade and spectroscopy (master equation, co-tunneling and Kondo effect); conductance and noise of point contacts; molecular transport; superconducting grains, Josephson junctions, and quantum bits;Nano wires, edge states, and hybrid structures. The course is accompanied by a series of problem sets, which the students are supposed to prepare and hand in by the end of the semester.E. Akkermans, G. Montambaux, J.-L. Pichard, and J. Zinn-Justin: Mesoscopic Quantum Physics, North Holland, 1996.

Subject code	Subject name	Requirement	ECTS credit
BMETE15MF74	Computer Simulation in Physics	Mid-semester mark	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	THU:16:15-18:00(F3213)
Practice	T1	English	THU:18:15-19:00(F3213)

Subject code	Subject name	Requirement	ECTS credit
BMETE80MD00	Nuclear Physics	Exam	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	WED:08:15-11:00
Practice	T1	English	WED:11:15-12:00

Required prior knowledge: Basics of classical physics and of electrodynamics, basic concepts of quantum mechanics and statistical physics.Syllabus:1. Manipulating electrically charges particles. Thomson and Millikan experiment. Mass spectroscopy and atomic mass unit (mass-doublet method). Spatial resolution, de Broglie formula. Electrostatic accelerators: Cockroft-Walton, Van de Graaf, Tandem Van de Graaf. Resonance accelerators: linear accelerator, cyclotron, synchrotron. LHC.2. Size of the nucleus, Rutherford's experiment. Hofstädter experiments. Discovery of the neutron and the composition of the nucleus. Angular momentum and parity.3. Stability of the nucleus, nuclear mass, mass defect. Weizsäcker's semi-empirical binding energy formula. Types and main characteristics of radioactive decays. Exponential decay law, decay chains. (Radioactive dating.)4. Basic theory of beta decays. Fermi's Golden Rule, Fermi theory of beta-decay, allowed and forbidden transitions. Fermi and Gamow -Teller transitions. Parity non-conservation.5. Anti-neutrino and neutrino detection (Reines Cowan, and Davis experiments). Solar neutrino puzzle and the neutrino oscillation.6. Basic theory of alpha decays. Transition coefficients and alpha spectroscopy factor. Basic theory of gamma-decays. Classification of decay modes: „electric" and „magnetic" transitions. Selection rules.7. Probabilities of gamma-transitions and Weisskopf-units. Sum rules. Measurements of decay probabilities.8. Nuclear models: Fermi-gas, Shell-model.9. Basics of collective model. Rainwater approximation. Vibrations and rotations.10. Nuclear forces. Learning from the deuteron. Basic ideas of Yukawa theory. Charge independency and isospin.11. Nuclear reactions. Kinematics. Elastic scattering (of neutrons). Microscopic and macroscopic cross sections and their two additivities. Differential cross-sections. Excitation functions.12. Partial-wave approximation, Born approximation, Distorted Wave Born Approximation.13. Mechanism and characteristics of nuclear fission. Nuclear chain reaction and some safety considerations.14. Nuclear fusion and the working principles of fusion devices. JET and ITER.

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX02	Mathematics A2a - Vector Functions	Exam	6

Course type	Course code	Course language	Timetable information
Lecture	EN0-EMK	English	MON:16:15-18:00(ONLINE); MON:16:15-18:00(ONLINE); TUE:16:15-18:00(ONLINE); TUE:16:15-18:00(ONLINE)
Practice	EN1-EMK	English	WED:16:15-18:00(ONLINE); WED:16:15-18:00(ONLINE)
Practice	EN2-EMK	English	WED:16:15-18:00(ONLINE); WED:16:15-18:00(ONLINE)

Solving systems of linear equations: elementary row operations, Gauss-Jordan- and Gaussian elimination. Homogeneous systems of linear equations. Arithmetic and rank of matrices. Determinant: geometric interpretation, expansion of determinants. Cramer's rule, interpolation, Vandermonde determinant. Linear space, subspace, generating system, basis, orthogonal and orthonormal basis. Linear maps, linear transformations and their matrices. Kernel, image, dimension theorem. Linear transformations and systems of linear equations. Eigenvalues, eigenvectors, similarity, diagonalizability. Infinite series: convergence, divergence, absolute convergence. Sewuences and series of functions, convergence criteria, power series, Taylor series. Fourier series: expansion, odd and even functions. Functions in several variables: continuity, differential and integral calculus, partial derivatives, Young's theorem. Local and global maxima / minima. Vector-vector functions, their derivatives, Jacobi matrix. Integrals: area and volume integrals.

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX07	Mathematics A3 for Civil Engineers	Exam	4

Course type	Course code	Course language	Timetable information
Lecture	EA0	English	TUE:16:15-18:00(ONLINE); TUE:16:15-18:00(ONLINE)
Practice	EA1	English	FRI:15:15-17:00(ONLINE); FRI:15:15-17:00(ONLINE)

Differential geometry of curves and surfaces. Scalar and vector fields. Potential theory. Classification of differential equations. Linear differential equation of the second order. Nonlinear differential equations. Systems of linear differential equations. The concept of probability. Discrete random variables an their distributions. Random variables of continuous distribution. Two-dimensional distributions, correlation and regression. Basic notions of mathematical statistics.

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX17	Mathematics A2c	Exam	6

Course type	Course code	Course language	Timetable information
Lecture	EN0-CA0	English	TUE:16:15-19:00; WED:16:15-19:00
Practice	EN0-CA1	English	TUE:16:15-19:00; WED:16:15-19:00

Differential calculus of functions of several variables: partial derivatives, differentiability, tangent plane. Derivatives of composite functions. Local and global maxima / minima. Inverse function, implicit function. Double and triple integrals. (5 weeks) Numerical series, power series, Taylor series. (2 weeks) Laplace and Fourier transform. (1 week) Linear algebra. Vectors, applications in geometry. Systems of linear equations. (3 weeks). Differential equations (separable differential equations, first order linear differential equations, second order linear differential equations with constant coefficients). (3 weeks)

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX22	Calculus 2 for Informaticians	Mid-semester mark	6

Course type	Course code	Course language	Timetable information
Lecture	EN0-EB0	English	MON:10:15-12:00; TUE:10:15-12:00
Practice	EN1-EB1	English	THU:14:15-16:00

Differential equations: Separable d.e., first order linear d.e., higher order linear d.e. of constant coefficients. Series: Tests for convergence of numerical series, power series, Taylor series. Functions of several variables: Limits, continuity. Differentiability, directional derivatives, chain rule. Higher partial derivatives and higher differentials. Extreme value problems. Calculation of double and triple integrals. Transformations of integrals, Jacobi matrix. Analysis of complex functions: Continuity, regularity, Cauchy - Riemann partial differential equations. Elementary functions of complex variable, computation of their values. Complex contour integral. Cauchy - Goursat basic theorem of integrals and its consequences. Integral representation of regular functions and their higher derivatives (Cauchy integral formulae).

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX26	Mathematics A2f - Vector Functions	Mid-semester mark	6

Course type	Course code	Course language	Timetable information
Lecture	EN0-VIK	English	MON:10:15-12:00; WED:08:15-10:00
Practice	EN1-VIK	English	WED:10:15-12:00

Solving systems of linear equations: elementary row operations, Gauss-Jordan- and Gaussian elimination. Homogeneous systems of linear equations. Arithmetic and rank of matrices. Determinant: geometric interpretation, expansion of determinants. Cramer's rule, interpolation, Vandermonde determinant. Linear space, subspace, generating system, basis, orthogonal and orthonormal basis. Linear maps, linear transformations and their matrices. Kernel, image, dimension theorem. Linear transformations and systems of linear equations. Eigenvalues, eigenvectors, similarity, diagonalizability. Infinite series: convergence, divergence, absolute convergence. Sewuences and series of functions, convergence criteria, power series, Taylor series. Fourier series: expansion, odd and even functions. Functions in several variables: continuity, differential and integral calculus, partial derivatives, Young's theorem. Local and global maxima / minima. Vector-vector functions, their derivatives, Jacobi matrix. Integrals: area and volume integrals.

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX34	Mathematics EP2	Mid-semester mark	2

Course type	**Course code**	**Course language**	**Timetable information**
Practice	EN1	English	

Limit, continuity, partial derivatives and differentiability of functions of multiple variables. Equation of the tangent plane. Local extrema of functions of two variables. Gradient and directional derivative. Divergence, rotation. Double and triple integrals and their applications. Polar coordinates. Substitution theorem for double integrals. Curves in the 3D space, tangent line, arc length. Line integral. 3D surfaces. Separable differential equations, first order linear differential equations. Algebraic form of complex numbers. Second order linear differential equations with constant coefficients. Taylor polynomial of exp(x), sin(x), cos(x). Eigenvalues and eigenvectors of matrices.

Subject code	Subject name	Requirement	ECTS credit
BMETE90AX51	Mathematics A4 - Probability Theory	Exam	4

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	EN0-A0	English	
Practice	EN1-A1	English	

Notion of probability. Conditional probability. Independence of events. Discrete random variables and their distributions (discrete uniform distribution, classical problems, combinatorial methods, indicator distribution, binomial distribution, sampling with/without replacement, hypergeometrical distribution, Poisson distribution as limit of binomial distributions, geometric distribution as model of a discrete memoryless waiting time). Continuous random variables and their distributions (uniform distribution on an interval, exponential distribution as model of a continuous memoryless waiting time, standard normal distribution). Parameters of distributions (expected value, median, mode, moments, variance, standard deviation). Two-dimensional distributions. Conditional distributions, independent random variables. Covariance, correlation coefficient. Regression. Transformations of distributions. One- and two-dimensional normal distributions. Laws of large numbers, DeMoivre-Laplace limit theorem, central limit theorem. Some statistical notions. Computer simulation, applications.

Subject code	Subject name	Requirement	ECTS credit
BMETE90MX44	Mathematics M1c - Differential Equations	Exam	3

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	EN-CA0	English	WED:08:15-10:00
Practice	EN-CA1	English	WED:10:15-12:00

Preliminaries: one- and multivariate calculus, elements of linear algebra. Explicit first order ordinary differential equations and it solution. Simple types. Linear systems. Higher order equations. Laplace transform, properties and applications. Elements of the qualitative theory. On partial differential equations. Elements of variational calculus.

Subject code	Subject name	Requirement	ECTS credit
BMETE93BG02	Mathematics G2	Exam	6

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	EN0-GPK	English	WED:16:15-19:00; THU:16:15-17:00
Practice	EN1-GPK	English	THU:17:15-19:00

Solving systems of linear equations: elementary row operations, Gauss-Jordan- and Gaussian elimination. Homogeneous systems of linear equations. Arithmetic and rank of matrices. Determinant: geometric interpretation, expansion of determinants. Cramer's rule, interpolation, Vandermonde determinant. Linear space, subspace, generating system, basis, orthogonal and orthonormal basis. Linear maps, linear transformations and their matrices. Kernel, image, dimension theorem. Linear transformations and systems of linear equations. Eigenvalues, eigenvectors, similarity, diagonalizability. Infinite series: convergence, divergence, absolute convergence. Sequences and series of functions, convergence criteria, power series, Taylor series. Fourier series: expansion, odd and even functions. Functions in several variables: continuity, differential and integral calculus, partial derivatives, Young's theorem. Local and global maxima / minima. Vector-vector functions, their derivatives, Jacobi matrix. Integrals: area and volume integrals.

Subject code	Subject name	Requirement	ECTS credit
BMETE95AM30	Probability Theory 2	Exam	4

Course type	**Course code**	**Course language**	**Timetable information**
Lecture	T0	English	MON:10:15-12:00
Practice	T1	English	TUE:10:15-12:00

Subject code	Subject name	Requirement	ECTS credit
BMETE95AM31	Mathematical Statistics 1	Exam	5

Course type	Course code	Course language	Timetable information
Lecture	EN0	English	THU:12:15-14:00(H405A)
Practice	EN1	English	THU:08:15-10:00(H601)

Statistical sample, descriptive statistics, empirical distributions. Most frequently used probabilictic models, likelihood function, sufficiency, maximum likelihood principle. Theory of point estimation: unbiased and asymptotically unbiased estimators, efficiency, consistency. Methods of point estimation: maximum likelihood, method of moments, Bayes principle. Interval estimation, confidence intervals. Theory of hypothesis testing, likelihood ratios. Parametric inference: u, t, F tests, comparing two treatments. Two-way classified data, contingency tables, chi-square test. Nonparametric inference: Wilcoxon and sign tests, Spearman correlation. Regression analysis. Linear regression, method of least squares, Pearson correlation. Multivariate regression, multiple correlation. Linear models, analysis of variance for one- and two-way classified data. Practical considerations: selecting the sample size, test for normality, resampling methods. – R. A. Johnson, G. K. Bhattacharyya, Statistics. Principles and methods. Wiley, New York, 1992.– G. K. Bhattacharyya, R. A. Johnson: Statistics – Principles and Methods, Wiley, 2014.

Subject code	Subject name	Requirement	ECTS credit
BMETE95MM07	Markov Processes and Martingales	Exam	5

Course type	Course code	Course language	Timetable information
Lecture	T0	English	
Practice	T1	English	

1. Martingales:Review (conditional expectations and tower rule, types of probabilistic convergences and their connections, martingales, stopped martingales, Doob decomposition, quadratic variation, maximal inequalities, martingale convergence theorems, optional stopping theorem, local martingales). Sets of convergence of martingales, the quadratic integrable case. Applications (e.g. Gambler's ruin, urn models, gambling, Wald identities, exponential martingales). Martingale CLT. Azuma-Houml;ffding inequality and applications (e.g. travelling salesman problem)2. Markov chains:Review (definitions, characterization of states, stationary distribution, reversibility, transience-(null-)recurrence). Absorbtion probabilites. Applications of martingales, Markov chain CLT. Markov chains and dynamical systems; ergodic theorems for Markov chains. Random walks and electric networks 3. Renewal processes:Laplace transform, convolution. Renewal processes, renewal equation. Renewal theorems, regenerative processes. Stationary renewal processes, renewal paradox. Examples: Poisson process, applications in queueing4. Point processes:Definition of point processes. The Poisson point process in one and more dimensions. Transformations of the Poisson point process (marking and thinning, transforming by a function, applications). Point processes derived from the Poisson point process. 5. Discrete state Markov processes:Review (infinitesimal generator, connection to Markov chains, Kolmogorov forward and backward equations, characterization of states, transience-(null-)recurrence, stationary distribution). Reversibility, MCMC. Absorption probabilities and hitting times. Applications of martingales (e.g. compensators of jump processes). Markov processes and dynamical systems; ergodic theorems for Markov processes. Markov chains with locally discrete state space: infinitesimal generator on test functions References:Karlin, S.; Taylor, H. M.: Sztochasztikus folyamatok. Gondolat Kiadoacute;, Budapest, 1985Lindvall, T.: Lectures on the Coupling Method. Dover Publications, Inc., Mineola, NY, 2002Norris, J. R.: Markov chains. Cambridge University Press, Cambridge, 1998 Resnick, S.: Adventures in Stochastic Processes. Birkhauml;user Boston, 1992 Rosenblatt, M.: Markov processes. Structure and Asymptotic Behavior. Springer-Verlag, New York-Heidelberg, 1971 Williams, D.: Probability with Martingales. Cambridge University Press, 1991

Subject code	Subject name	Requirement	ECTS credit
BMETE95MM11	Stochastic Models	Mid-semester mark	2

Course type	Course code	Course language	Timetable information
Lecture	T0	English	

Coupling methods (stochastic dominance, coupling random variables and stochastic processes, examples: connectivity using dual graphs, optimization problems, combinatorial probability problems)Percolation (definitions, correlation inequalities, duality, contour methods)Strongly dependent percolation: Winkler percolation, compatible 0-1 sequencesBasics of statistical physics (Gibbs measure, a few basic models)Card shuffling (completely shuffled deck, how many times should one shuffle?)Random graph models (Erdősndash;Reacute;nyi, Barabaacute;sindash;Albert; basic phenomena)Variants of random walks: scenery reconstruction, self-avoiding eacute;s self-repelling walks, loop -erased walks, random walk in random environment)Queueing models and basic behavior; stationary distribution and reversibility, Burke Theorem; systems of queuesInteracting particle systems (simple exclusion on the torus and on the infinite lattice, stationary distribution, Palm distributions, couplings, other models)Graphical construction of continuous time Markov processes (Yule model, Hammersley's process, particle systems)Self organized criticality: sandpile models (questions of construction, commutative dynamics, stationary distribution in finite volume, power law decay of correlations)Linear theory of stationary processes: strongly and weakly stationary processes, spectral properties, autoregressive and moving average processes. Analysis of time series, long memory processes.Models of risk processes. References: (Selected chapters from the following ndash; and other ndash; works.) Grimmett, G.: Percolation. Springer-Verlag, Berlin, 1999. Liggett, T.: Interacting Particle Systems. Springer-Verlag, Berlin, 2005.

Lindvall, T.: Lectures on the Coupling Method. Dover Publications, Inc., Mineola, NY, 2002. Thorisson, H.: Coupling, Stationarity, and Regeneration. Springer-Verlag, New York, 2000. Walrand, J.: An Introduction to Queueing Networks. Prentice Hall 1988Werner, W.: Lectures on Two-dimensional Critical Percolation, http://arxiv.org/abs/0710.0856Werner, W.: Random Planar Curves and Schrammndash;Loewner Evolutions, http://arxiv.org/abs/math/0303354Zeitouni, O.: Lecture Notes on Random Walks in Random Environment, XXXI summer school in probability, St Flour, France, Volume 1837 of Springer's Lecture notes in Mathematics

Subject code	Subject name	Requirement	ECTS credit
BMETE95MM12	Advanced Theory of Dynamical Systems	Mid-semester mark	2

Course type	Course code	Course language	Timetable information
Lecture	T0	English	

Subadditive and multiplicative ergodic theorems. Lyapunov exponents. Spectral properties of measure preserving transformations. Shadowing lemma. Markov partitions and their construction for uniformly hyperbolic systems. Perron-Frobenius operator and its spectrum. Doeblin-Fortet inequality.Stochastic properties of hyperbolic dynamical systems. Kolmogorov-Sinai entropy. Ornstein’s isomorphy theorem (without proof).M. Pollicott: Lectures on Ergodic theory and Pesin Theory on compact manifolds, CUP, 1993.R. Bowen: Equilibrium states and the ergodic theory of Anosov diffeomorphisms, Springer LNM 470, 1975. M. Brin, G. Stuck: Introduction to Dynamical Systems, CUP, 2002.

Subject code	Subject name	Requirement	ECTS credit
BMETE95MM34	Markov Decision Processes and Reinforcement Learning	Exam	3

Course type	Course code	Course language	Timetable information
Lecture	T0	English	

General theory of MDPs:Basic concepts of Markov Decision Processes (MDPs), main types such, as stochastic shortest path, total discounted and average (ergodic) cost problems. Control policies, value functions, Bellman operators and their core properties, monotonicity, contraction, optimality equations, greedy policies and approximation possibilities. Existence and properties of optimal control policies.Standard RL methods for MDPs:Main solution directions of MDPs: iterative approximations of value functions (e.g., value iteration, Q-learning, SARSA); direct search in the space of policies (e.g., policy iteration, policy gradient); linear programming formulation, complexity. Generalizations: unbounded costs, partial observability.Temporal difference (TD) learning based policy evaluations: Monte Carlo methods, eligibility traces, TD(0), TD(1) and TD(lambda): online, offline, first-visit, every-visit variants, convergence theorems, optimistic policy improvements. Examples, like Q-learning for SSPs. Off-policy policy evaluations.Small-sample theory for RL:Multi-armed bandit problems, exploration-vs-exploitation, regret, Hannan consistency, canonical bandit model, subgaussian bandits, explore-then-commit algorithm, upper confidence bound (UCB) algorithm, the optimism principle, regret bounds for UCB, asymptotic optimality of UCB, contextual bandits, stochastic linear bandits, confidence regions for bandit problems, online confidence sets.Large-sample theory for RL:General adaptive algorithms and stochastic approximation (SA), fixed point and root finding problems. Examples of classical SA algorithms with analogous methods in RL: Robbins-Monro (e.g., Q-learning), Kiefer-Wolfowitz (e.g., policy gradient), SPSA (simultaneous perturbation stochastic approximation), stochastic gradient descent (SGD) and its acceleration methods (e.g., momentum).Asymptotic analysis of general adaptive algorithms assuming martingale difference noise sequences. Convergence results based on Lyapunov (potential) functions. Applications to classical examples: SGD with Lipschitz continuous gradient and Euclidean norm pseudo-contractions. Convergence analysis based on contraction and monotonicity properties, and their illustration through RL examples.Recommended literature:Bertsekas D. P. amp; Tsitsiklis J. N.: Neuro-Dynamic Programming, Athena Scientific, 1996.Lattimore, T. amp; Szepesvári, Cs.: Bandit Algorithms, Cambridge University Press, 2018.Feinberg, A. E. amp; Shwartz, A. (eds.): Handbook of Markov Decision Processes, Kluwer Academic Publishers, 2002.Kushner, H. amp; Yin, G.: Stochastic Approximation and Recursive Algorithms and Applications, 2nd edition, Springer, 2003.Sutton, R. S. amp; Barto, A. G: Reinforcement Learning: An Introduction, 2nd edition, MIT Press, 2018.

Subject code	Subject name	Requirement	ECTS credit
BMETE95MM41	Stochastic Analysis	Exam	8

Course type	Course code	Course language	Timetable information
Lecture	T0	English	
Practice	T1	English	

1) Martingales, discrete stochastic integral, optional stopping theorem, discrete Doob decomposition.2) Multivariate normal distribution, Gaussian process, Paul Lévy's construction of Brownian motion.3) Martingales derived from Brownian motion, properties of Brownian motion, B.M. is nowhere differentiable.4) Stieltjes integral, quadratic variation (e.g. of Brownian motion), mutual variation.5) Strong Markov property, reflection principle for Brownian motion.6) Definition of Ito integral (w.r.t. Brownian motion), case of deterministic integrand (Gaussian process), martingale property of Ito integral, quadratic variation of Ito integral.7) Def of Ito process, Ito formula (in the case when we integrate w.r.t. B.M.)8) Stochastic integral w.r.t. Ito process, Ito formula for Ito processes.9) Stochastic integration by parts, time-dependent Ito formula, multivariate Ito formula.10) Harmonic functions and martingales.11) Paul Lévy's characterization of B.M.12) Martingale representation theorem.13) Existence and uniqueness of strong

solution of stochastic differential equation.14) Famous stochastic differential equations (SDEs): O-U process, Geometric Brownian motion, Brownian bridge.15) Equivalent definitions and properties of Besssel process, relation of squared Bessel process and branching processes.16) Stochastic exponential and stochastic logarithm.17) General linear SDE, stochastic logistic equation, CIR process.18) Infinitesimal generator of diffusion process, Dynkin's formula.19) Weak solution of SDE, Tanaka's counterexample, Tanaka's formula.20) Diffusions and related elliptic PDE's (Laplace, Poisson, Helmholtz).21) Diffusions and related parabolic PDE's (heat equation, Kolmogorov forward/backward, Feynman-Kac formula).22) Stationary distribution of 1-dimensional diffusion process.23) Change of measure, Girsanov's formula.– H-H. Kuo, Introduction to Stochastic Integration, Springer, 2008.– F.C. Klebaner, Introduction to stochastic calculus with applications, (Third edition) Imperial College Press, 2012.– Durrett, Richard. Stochastic calculus: a practical introduction. Vol. 6. CRC press, 1996.

Subject code	Subject name	Requirement	ECTS credit
BMETETOP201	Vibration, Waves and Thermodynamics	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	T0	English	
Practice	T2	English	
Practice	T1	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOP202	Optics and Atomic Physics	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	A0	English	
Practice	A3	English	
Practice	A1	English	
Practice	A2	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOP203	Algebra 2	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	A1	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOP204	Geometry 2	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	A1	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOP205	Computing	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	A0	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOP208	Advanced Algebra	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	A0	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOP209	Computer Algebra	Exam	0

Course type	Course code	Course language	Timetable information
Lecture	A1	English	

Subject code	Subject name	Requirement	ECTS credit
BMETETOPB22	Basic Mathematics 1	Mid-semester mark	0

Course type	Course code	Course language	Timetable information
Lecture	EN0-A0	English	WED:17:15-19:00(ONLINE); WED:17:15-19:00(ONLINE); THU:17:15-19:00(ONLINE); THU:17:15-19:00(ONLINE)

Algebra part. Integers, rational, real numbers. Arithmetic operations and their properties. Prime factorization. Powers. Working with arithmetic expressions. Equations of first degree and second degree. Equations with radicals. Factoring polynomials. Notion of sets. Set operations and their properties. Inequalities. Word problems. Geometry part. Basic notions: lines, angles. Triangles (equilateral, isosceles, right triangles, bisector, altitude, etc. in triangles). Circles. Circumscribed and inscribed circles of triangles. Tangents to circles, angles of circumference. Angles in radian. Perimeter and area of planar figures. Sine, cosine, tangent of angles in right triangles and in triangles with obtuse angle. Sine theorem, Cosine theorem. Parallelograms. Sphere, tetrahedron, prism, cylinder, pyramid, cone, parallelepiped. Surface area and volume. Cartesian coordinate system. Area and volume of similar figures.