Applied Mathematical and Physical Sciences

Five-year M.Sc. studies
School of Applied Mathematical and Physical Sciences
National Technical University of Athens

Athens, September 8, 2010

Semester 1:

- Mathematical analysis I (78h lectures)
- Analytic Geometry and Linear Algebra (65h lectures)
- Physics I (Mechanics) (78h lectures)
- Mechanics I (52h lectures)
- Introduction to Programming (65h lectures)
- Microeconomic Theory (26h lectures)

Semester 2:

I. Core Courses

- Mathematical analysis II (65h lectures)
- Linear Algebra and Applications (52h lectures)
- Physics II (Electromagnetism) (65 lectures)
- Physics Laboratory I (26h laboratory)
- Mechanics II (Deformable Body) (52h lectures)
- Design and Development of Computer Applications (65h lectures)

II. Elective Courses

Students should also choose one from the following courses:

- Introduction to the History of Sciences and Technology (26h lectures)
- History of Economic Theories (26h lectures)

Semester 3:

- Mathematical Analysis III (52h lectures)
- Ordinary Differential Equations (52h lectures)
- Probability (39h lectures)
- Physics III (Waves) (65h lectures)
- Physics Laboratory II (26h laboratory)
- Mechanics III (Kinematics and Dynamics) (52h lectures)
- Introduction to Philosophy (26h lectures)

Semester 4:

I. Core Courses

- Numerical Analysis I and Laboratory (52h lectures)
- Complex Analysis (52h lectures)
- Statistics (39h lectures)
- Physics IV (Quantum Mechanics I) (65h lectures)
- Introduction to Computer Science (65h lectures)
- Structural Mechanics (52h lectures)
- Scientific Terminology (26h lectures)

II. Elective Courses

Students should also choose one from the following courses:

- Sociology (of Science) (26h lectures)
- Macroeconomics Theory (26h lectures)
- Philosophy of Sciences (26h lectures)

Semester 5, direction of Applied Physics:

- Partial Differential Equations (52h lectures)
- Quantum Mechanics II (52h lectures)
- Condensed Matter Physics (52h lectures)
- Thermodynamics (39h lectures)
- Electronics – Laboratory (52h lectures and laboratory)
- Physics Laboratory III (26h laboratory)
- General chemistry (39h lectures)

Semester 6, direction of Applied Physics:

I. Core Courses

- Electromagnetism II (52h lectures)
- Optics and Optics Laboratory (26h lectures+26h laboratory)

- **Atomic and Molecular Physics (52h lectures)**

Elements of Quantum Mechanics. Introduction to the structure of atoms and molecules: (a) One-electron atoms, atomic orbitals, analytical and numerical solutions, (b) the one -electron molecule H^+_2, molecular orbitals, chemical bond (I), (c) Many-electron atoms, central field, Hartree – Fock theory, open shells, momentum coupling. Perturbation theory, calculus of variations and elementary applications. Interaction with external fields – lasers. Elements of atomic and molecular spectroscopy. Introduction to scattering theory – resonance states.

II. Elective Courses

Students should also choose four from the following courses:

- Experimental Physics Techniques (52h lectures)
- Dielectric, Optical and Magnetic Properties of Materials (52h lectures)
- Group Theory in Physics (Symmetries in Physics) (52h lectures)
- Principles of Microwave Transmission and Optical Signals (52h lectures)
- Solid State Chemistry (52h lectures)
- Automatic Control I (52h lectures)
- History of Physics in the 19^{th} and 20^{th} Century (52h lectures)

Semester 7, direction of Applied Physics:

I. Core Courses

- Statistical Physics (52h lectures)
- **Nuclear Physics and Elementary Particles (52h lectures)**

Introduction to the nucleus: radius, mass, charges, binding energy. Stability of the nucleus. Shell model, magical numbers. Angular momentum, spin, coupling, electric and magnetic moments. α, β, γ decay. Dosimetry. Fission, fusion, nucleosynthesis. Introduction to elementary particles. Properties and classification. Conservation laws. Hadron interactions at high energies. Fundamental quark model. Fundamental interactions: elecromagnetic, weak and strong. Unification of fundamental interactions. Nuclear and particle astrophysics.

II. Elective Courses

Students should also choose five from the following courses:

- Computational Physics I (52h lectures)
- Introduction to Astrophysics (52h lectures)
- Non-destructive Testing of Materials-Ultrasounds (52h lectures)

- Introduction to Communication Networks (52h lectures)
- Introduction to Anelastic Behavior of Materials (52h lectures)
- Philosophy of Physics (52h lectures)
- Business Economics (52h lectures)
- Introduction to Sociology of Industrial Research (52h lectures)
- **Optoelectronics (52h lectures)**

Physical optics, photons, optical absorption mechanisms, photoconductivity mechanisms, optical and optoelectronic materials, spontaneous and stimulated emission, absorption, fluorescence, phosphorescence, luminescence, coherent and incoherent sources, displays, radiation detectors, noise and electronics of detectors, image intensifiers, I2 devices, thermal imagers, couplers, modulators, liquid crystals, integrated optics, photonic logic, introduction to optical fibers – optical communications, introduction to lasers and their applications.

- **Applications of Ionizing Radiation in Medicine and Biology (52h lectures)**

Principles of the Physics of ionizing radiation. Ionizing radiation characteristics as properties of the atomic nucleus. Theory of the interaction of ionizing radiation with matter.Nuclear reactions and isotope production. Clinical application of radioisotopes and radiopharmaceuticals. Detector instrumentation for the three fundamental types of radiation, α, β, and γ. Ionizing radiation effects on biological organisms. Biological effect of neutrons and their use in clinical medicine. Advanced techniques for clinical applications and the use of accelerating devices. Introduction to dosimetry and radiation protection.

- **Semiconductors and Semiconducting Devices (52h lectures)**

INTRODUCTION. STRUCTURE AND PROPERTIES, ENERGY BANDS: (Conductivity Zone and electrons, Valence Zone and Holes, Direct-Indirect energy Gap, Effective mass (mt, ml, mlh, mhh, msoh), Density of States, DoS Effective Mass, Optical Properties – Excitons. HOMOGENEOUS SEMICONDUCTORS. Intrinsic: (Fermi level, Carrier concentrations, n-, p-type). Extrinsic: (Donors – Acceptors, Dopants energy states, Fermi level, carrier concentrations). TRANSPORT PROPERTIES: Drift of carriers (conductivity current), Hall effect, Diffusion of carriers, (diffusion current), Carrier injection, Carrier Generation-Recombination, Einstein relation, Continuity equation. CARRIER SCATTERING MEACHANISMS: Lattice Vibrations ($T\neq0$), Ionized Doping-atoms. INHOMOGENEOUS SEMICONDUCTORS: In thermal equilibrium (Fermi level, Band-bending, Space-charge electric-field). p-n JUNCTION: Equilibrium state (Fermi level, Contact Potential), Biased p-n junction (Forward – Reverse, $I=I(V)$ characteristic). _ Low-dimensional semiconductor structures, Quantum Wells, Quantum Wires, Quantum Dots: Electronic properties. 2-dimensional Hall effect, 2-Dimensional Magnetoresistance.

- **Characterization Methods of Materials (52h lectures)**

Structural characterization: X ray diffraction, electron diffraction, Auger electron diffraction, Nuclear spectroscopy, Microscopy (electron, tunnel effect and atomic force) *Thermal characterization*: Differential thermal analysis, differential scanning calorimetry, Dynamic mechanical analysis, Thermo-gravitational analysis. Dielectric spectroscopy, Nuclear magnetic resonance, electronic paramagnetic resonance, Mossbauer spectroscopy.

Optical characterization: Infrared spectroscopy, Raman spectroscopy, Ellipsometry, modulated reflectivity spectroscopy, Photoluminescence and electroluminescence spectroscopy. _ Non-destructive testing, choice of optimal material, design and development of new materials.

Laboratory exercises: X ray diffraction, X ray fluorescence, differential scanning calorimetry, Dynamic mechanical analysis, Dielectric spectroscopy, Nuclear magnetic resonance, luminescence of compact conducting and semiconducting structures, modulated photoreflectivity of complex semiconductors, production of thin films in a sublimation system with an electron beam, optical measurements of thin film thickness (ellipsometry).

Semester 8, direction of Applied Physics:

I. Elective Courses

Students should choose six from the following courses:

- Physics Seminar (26h lectures)
- Theoretical Physics (52h lectures)
- Signal Analysis (52h lectures)
- Physics and Technology of Lasers (52h lectures)
- Polymers and Composites (52h lectures)
- Biophysics (52h lectures)
- Continuous Groups (52h lectures)
- New Technologies in Education (52h lectures)
- History of Physics 19^{th} and 20^{th} Century (52h lectures)

- **Introduction to Medical Imaging (52h lectures)**

Introduction to Medical Imaging Systems: Computed Tomography (CT), Magnetic Resonance Imaging (MRI), endoscopy systems, ultrasound imaging (US).

Medical image reconstruction methods: Image reconstruction algorithms (simple back projection, filtered back projection, iterative reconstruction algorithms), artefacts in the reconstructed images, three dimensional tomography.

Computed Tomography: Physical principles of operation, X-ray Computed Tomography instrumentation, data acquisition geometries, tomographic image reconstruction, helical CT.

Nuclear Medicine and Single Photon Emission Computed Tomography (SPECT): Radiopharmaceuticals, Auger Camera, operation principles, SPECT instrumentation and image reconstruction.

Positron Emission Tomography (P.E.T.): Physical principles, radiopharmaceuticals, instrumentation, image reconstruction, clinical applications.

Nuclear Magnetic Resonance (NMR): Principles, Bloch equation solutions, detecting systems, pulse sequences, relaxation processes and their measurement, NMR imaging equation.

Ultrasound Imaging Methods: Physical principles, production and detection, pulse – echo US imaging, Real time ultrasound tomography imaging, ultrasonic Doppler imaging, ultrasound tomography, evaluation of ultrasonic imaging methods.

Diffraction Tomography: Projections to diffraction tomography, approximate solutions of the wave equation, Fourier's diffraction theorem, reconstruction algorithms.

Interaction of RF electromagnetic waves with Biological Tissue: Electrical properties of biological tissue, biological effects of electromagnetic waves, dosimetry magnitudes and safe exposure limits to electromagnetic waves.

- **Detecting and Accelerating Systems (52h lectures)**

Interaction of radiation with matter: Interaction of x and γ ray radiation with matter. Interaction of charged particles with matter.

Detectors: Gas – scintillation - solid state and other detectors. Detection of x and γ ray radiation. Detection of charged particles. Neutron detection. Detecting devices in high-energy experiments: trajectory detectors, energy detectors (calorimeters), muon detectors, magnets, Cerenkov detectors, gas detectors.

Accelerators: Electrostatic accelerator. Beam transfer. Linear detectors. Cyclotron Sychnotron. Colliding beam detectors.

Data acquisition: Triggering and data recording conditions. Data analysis techniques and simulation methods.

Experiments: Description of typical experiments.

- **Nuclear Physics and Applications (52h lectures)**

Nuclear reactions – cross section. Nuclear decay law. Bound states of nucleons – deuterium – nucleon exchange forces. Nuclear models (liquid drop, shell, collective). Nuclear deformation Electric and magnetic multipoles. γ ray emission. Nuclear magnetic resonance. Rutherford scattering. Nuclear reactions. Applications of Nuclear Physics in the study of materials (RBS, ERDA, PIXE, etc.), in medicine (diagnosis – therapy), to the environment, in archaeometry, in industry.

Semester 9, direction of Applied Physics:

I. Elective Courses

Students should choose six from the following courses:

- Computational Physics II, Modeling (52h lectures)
- Elementary Particles (52h lectures)
- Pattern Recognition and Neural Networks (52h lectures)
- Application of Laser in Biomedicine and the Environment (52h lectures)
- Ceramics and Dielectric Materials (52h lectures)
- Microsystems Technology (52h lectures)
- Relativity (52h lectures)
- Environmental Physics (52h lectures)
- Introduction to Medical Physics (52h lectures)
- Introduction to Wide World Web Technologies (52h lectures)
- Fluid Mechanics (52h lectures)
- Law (52h lectures)
- Environmental Policy (52h lectures)
- **Nuclear Engineering (52h lectures)**

Nuclear reactions with neutrons. Fission. Scattering, diffusion, absorption, thermalization of neutrons. Criticality analysis for bare homogeneous thermal neutron systems. Nuclear Power Reactors. Nuclear Power Plants. Nuclear fuel. Steady-state heat removal from the nuclear power reactor core. Thermodynamic cycles and energy production. Nuclear installations safety, nuclear accidents. Fission products dispersion in the environment. Industrial applications of nuclear engineering. Principles of radiation protection and radioenvironmental analysis.