NUCLEAR ENGINEERING AND NUCLEAR CHEMISTRY

Three-year B.Sc. studies held at the
Faculty of Chemistry and Faculty of Physics at the University of Warsaw
since the academic year 2011/12.

Additional courses, such as sport and foreign languages, are not included.

Warsaw, March 28, 2010

SEMESTER 1

Differential and integral calculus (90h lectures + 90h exercises)

Algebra with geometry (30h lectures + 30h exercises)

Organic chemistry with elements of biochemistry (30h lectures + 90h laboratory)

SEMESTER 2

Mathematical analysis (75h lectures + 60h exercises)

Mechanics and special theory of relativity (60h lectures + 45h exercises)

Physical chemistry (30h lectures + 15h exercises + 60h laboratory)

Laboratory of data analysis (15h)

SEMESTER 3

Electrodynamics (60h lectures + 60h exercises)

Introduction to modern physics (30h lectures)

Inorganic chemistry with elements of inorganic synthesis (30h lectures + 60h laboratory)

Laboratory of physics and electronics (15h lectures + 45h laboratory)

Introduction to subatomic physics (30h lectures + 30h exercises)
History of nuclear physics and of physics of elementary particles. Elementary constituents of matter and fundamental interactions. Symmetries and conservation laws. Standard Model. Reactions of elementary particles. Cross section. Relativistic and non-relativistic kinematics. Basic properties of atomic nuclei. Law of radioactive decay. Statictics in radioactivity. Chart of nuclids. Liquid-drop model. Valley of stability and mass parabolas. Alpha, beta, and gamma decays. Fission and chain reaction. Other kinds of radioactivity. Shell structure of atomic nuclei. Working principle of nuclear reactors. Elements of dosimetry. Radioactivity in natural environment.

SEMESTER 4

Quantum mechanics and chemistry with elements of molecular spectroscopy
(60h lectures, 60h exercises, 30h laboratory)

Crystallography with elements of group theory (15h lectures + 30h exercises)

Instumental analysis (15h lectures + 30h laboratory)

Applications of nuclear physics (30h lectures + 30h exrecises)
Interaction of radiation with matter. Detection and detectors. Accelerators and beam-guide systems. Electronics of measurement tracts. Basic information on nuclear medicine. Industrial applications of nuclear physics. Neutron Physics. Elements of reactor physics. Types and applications of reactors. Fuel cycle. Nuclear fuel and radioactive waste. Theronuclear reactions and fusion. Elements of plasma physics. Radioprotection and nuclear safety. Nuclear accidents and ecological aspects. Nuclear and conventional power, renewable sources of energy.

Radiological protection (30h lectures, 15h exercises, 30h laboratory)
Lectures: Atomic law. Basic international and european regulations. Permissions for work with radiation. Competences of radioprotection officers. Elements of work law. Limiting exposure. Dosimetric equipment. Principles of handling closed and open sources of radiation in laboratories and outside. Transportation of radioactive materials. Determination of doses and contamination. Control of exposure of workers and general public, including exposure to natural radiation. Determination of leakproofness of closed sources. General information on handling radioactive waste. Classification of radiation events. Emergency plan. Organization of radioprotection in a company unit. Duties and rights of unit's chief, radioprotection officer, and workers. Work under increased exposure to natural radiation. Basic documents. Code of practice, work instructions, dose register, source register. Rules of work with radiation-generating devices in laboratories and outside. Control of leakage. Dose limits. Dosimetric measurements in work environment. Establishing controled areas. Decontamination of equipment and people. Estimaion of general public exposure. Reference groups. Principles of work in X-ray and accelerator laboratories. Case-study of radiation events with radiation-generating devices. In-body contamination. Identification of radioactive substances and nuclear materials. Typical applications of nuclear techniques and associated risks. Basics of X-ray lamps and accelerator physics.

Exercises: Calculation of activity change in time, doses, and shields. Optimization of work conditions under exposure. Estimation of individual doses on the basis of dosimetric measurements in work environment. Determination of longest acceptable time of stay in a chamber of increased radioactivity. Estimation of in-body contamination. Estimation of dose for a reference group. Calculation of dose and dose power including those from scattered radiation. Calculation of shields and of work time in radiotherapy laboratories. Calculation of activity and concentration of radioisotopes in body and in waste typical for nuclear medicine.

Laboratory: Measurement of radiation spectra. Finding and identification of unknown source. Determination of shielding ability of various materials. Basic characteristics of scintillation counters. Adjusting settings of dosimetric counters. Measurment of dose power. Working principle of semiconductor detectors used for gamma radiation. Measurement of neutron flux. Measurement of radioactive contamination. Decontamination. Mapping isodoses. Dosimetric measurements in a radiochemical laboratory. Hot chambers, dosimetric gates. Dosimetric measurements in work environment. Transport of radiopharmaceuticals to application site.

SEMESTER 5

Introduction to thermodynamics and statistical physics (30h lectures + 30h exercises)

Introduction to astronomy and nuclear astrophysics (30h lectures)
Outline of history of astronomy. Sources of astronomical data and observational methods. Solar System, Galaxy, extra-galactic astronomy. Big Bang theory and cosmological models. Structure and evolution of stars. Interstellar matter. Abundance of chemical elements. Nucleosynthesis. Thermonuclear reactions. Burning of hydrogen. The p-p and CNO cycles. Burning of helium. Burning of heavier elements and explosive phenomena. Syntesis of elements heavier than iron. The s, r, and rp processes. Role of neutrinos in astrophysical processes.

Programming and numerical methods (30h lectures + 45h exercises)

Cell biology (15h lectures)

Advanced nuclear physics (30h lectures + 30h exercises + 60h laboratory)
Lectures and exercises: Nuclear matter. Fermi-gas model. Nucleon-nucleon interaction. Deuteron. Isospin. Elements of shell model. Dipole and quadrupole moments. Residual interactions. Pairing. Nilsson model of deformed nuclei. Nuclear vibrations and rotations. Classification of nuclear reactions. Methods for syntesizing exotic nuclids. Analysis of selected experiments in modern nuclear physics. Overview of current research in experimental and theoretical nuclear physics.

Laboratory (5 exercises to choose): Statistics in nuclear measurements (obligatory). Determination radon concentration in air. Determination of ^{40}K concentration in natural potasium. Determination of mangan concentration in steel by activation methods. Measurement of deuteron binding energy. Measurement of energy spectrum of fission fragments from thermal-neutron-induced ^{238}U fission. Determination of ^{128}I decay scheme. Analysis of Compton effect. Examination of energy spectrum of internal-conversion electrons. Measurement of stopping power and range of alpha particles in air. Measurements of absorbtion of gamma radiation in matter. Measurements of range of beta particles in matter.

Nuclear chemistry and radiochemistry (30h lectures + 60h laboratory)
Lectures: Natural background radiation and its components. Contribution from radioactive isotopes, cosmic rays. Origin of radioisotopes: man-made and anthropogenic radioisotopes. Synthesis of isotopes: Big Bang theory, stellar nucleosynthesis, natural radioactive decay chains, human activity, synthesis of new elements. Propagation of radionuclides in the environment, radon. Radiation detection, most common types of detectors: gas detectors (ionization chamber, proportional counter, GM counter), scintillation counters (various types of scintillators), semiconductor counters (HPGe, CZT, CdTe). Interpretation of γ-ray spectra. Radioactive isotopes and ionisation radiation in chemistry. Isotopic effect: influence on kinetics and physical properties, isotopic effect in spectroscopy. Elements without stable isotopes, actinides, transuranium elements: chemical and physical properties. Single atom chemistry. Chemical consequences of radioactive decays, hot atom chemistry, Szilard-Chalmers effect. Influence of radiation on chemical systems, radiolysis, free radicals chemistry, solvated electron, polymers radiochemistry. Mössbauer effect, hyperfine structures and interactions. Synthesis of radioactive labelled compounds: nuclear reactions, accelerators, chemical reactions. Isotopic exchange: mechanism and kinetics. Muonium chemistry. Isotope separation and enrichment. Radioactive isotopes and radiation in spectroscopy: Mössbauer spectroscopy: transmission spectroscopy and conversion electrons, Perturbed Angular Correlation - PAC, neutron diffraction (elastic, quasielastic, neutrons with various energies), Positron Annihilation Technique - PAT, Emission Channelling, muon spectrometry - μSR, Electron Capture Spectroscopy. Radioactive isotopes and radiation in chemistry: radioactive labelled compounds, identification of intermediates and final products of chemical reactions, investigation of kinetics of organic and inorganic reactions, dynamic equilibria and phase transitions, application of isotope effect, radionuclides in ex-situ and in-situ measurements. The most commonly used radioisotopes, muonium. Stable isotopes in kinetics studies, mass spectrometry. Radioactive isotopes and ionisation radiation in material science: determination of chemical composition, crystallographic structure determination, hydrogen bonds, hyperfine interactions and structures, selfdiffusion, trace diffusion, defects in semiconductors. Radioactive isotopes and ionisation radiation in geology, archaeology and palaeontology: radiocarbon dating, uranium-thorium radiometric dating, other dating methods: Sm-Nd, K-Ar, Rb-Sr, 36Cl, short-lived isotopes dating, radioactive isotopes in climate changes studies, γ-ray spectrometry in geological mapping. Radioactive isotopes and ionisation radiation in medicine: radiolabelled compounds - indicators, medical diagnostic imaging, PET, SPECT, external and internal radiation therapy, radiopharmaceutics and radiolabelled drugs, blood irradiation, bone density tests, radionuclide generators. Radioactive isotopes and radiation in quantitative and qualitative analysis: neutron activation analysis, PNAA, DNAA. Neutron sources, neutron reaction cross section. Gamma spectrometry in space investigations, quantitative analysis with other than semiconductor detectors. Other types of radiation in analytical chemistry, α particles emitters determination. Radioactive isotopes and radiation in industry: fire protection, thickness and quantity measurements, real-time wear measurement using radioactive tracers, radioactive isotopes in welding technology, food preservation, flowmeters, actinides applications not related to radiation. Nuclear power – basic aspects related to reactors and nuclear fuels. Nuclear weapon.

Laboratory (10 exercises to choose): Radiolysis of water. Isotope exchange. Radioactive isotopes in determination of chemical compounds structure. Determination of potassium compounds in natural products on the basis of measurements of ^{40}K activity. Radioactive isotopes in electrochemical studies. Synthesis of biologically active compounds labelled with 14C and 1H. Analysis of purity of radiolabelled chemical compounds. Determination of alpha particle emitters in environmental samples. Physical and chemical properties of transuranium elements. Positron emission tomography (PET) – presentation of diagnostic method: phantoms and animal PET scanner. Technetium generator - synthesis of ^{99m}Tc. Sample geometry in radiation measurements. HPGe detectors in qualitative and quantitative analysis. Determination of solubility constant of inorganic compounds. Determination of ionisation constant and distribution coefficient. Radioactive equilibrium. Metal-metal ion exchange in corrosion studies. Analysis of complex radioactive decays.

SEMESTER 6

Applied chemistry, waste and menagement of chemical substances (10h lectures)

Chemical technology (30h lectures + 30h laboratory)

Material chemistry and technology (30h lectures)

Students should also choose some from the following lectures to fill 60h:

Perception of nuclear power in the society (15h lectures)

Nuclear techniques in medical diagnostics and therapy (30h lectures)

Synthesis of radionuclides and their applications in nuclear medicine (30h lectures)

Isotopical effects in chemistry (30h lectures)

Nuclear fuel and waste from nuclear power (15h lectures)

Physics of the interior of Earth (30h lectures)

Physics of weather and climate (30h lectures)

Introduction to environmental physics (30h lectures)

Physical experiment under extreme conditions (30h lectures)

Neutrino physics (30h lectures)

Nuclear power and weapons (30h lectures)