# Surface and Plasma Physics

**Coordinated by:** Department of Surface and Plasma Science
**Study programme coordinator:** doc. RNDr. Jan Wild, CSc.

*Characterization of the study program:*

Surface and Plasma Physics is a master's degree program of an interdisciplinary nature, which includes fundamental knowledge of interactions of neutral and charged particles in vacuum, gas, and condensed phase and at the interfaces of these environments. The program provides expertise in the physics of surfaces and thin films, especially atomic and molecular nanostructures on solid surfaces with significant binding to physico-chemical and transport processes and with applications in the field of catalysts, sensors, or molecular electronics. Program in laboratory and space plasmas intervenes in plasma chemistry, laser mixtures, hot and fusion plasma, and some parts of astrophysics. During the study, it is possible to master the use of modern diagnostic methods in materials research, vacuum and plasma technologies, and the analysis of various types of space plasmas or controlled thermonuclear fusion. Individual disciplines can be oriented experimentally, theoretically, or solved by methods of computational physics.

*Profile of the graduates and aims of the study:*

The graduates of the study program Surface and Plasma Physics have a broad knowledge of the physical foundations of the field and demonstrate an understanding of the relevant mathematical apparatus, including applying it. They master advanced diagnostic methods and computer models, which allows them to understand the behavior of atomic and molecular structures on solid surfaces and the associated significant application problems as well as fundamental processes in ionized media typical for various fields from astrophysics to plasma chemistry and magnetohydrodynamics. The graduates are also able to independently formulate hypotheses, create computer simulations and critically analyze the outputs. They are prepared to present their findings and conclusions to the professional and lay public in the form of presentations or written texts, even in a foreign language. They also apply the acquired knowledge, skills, and creative abilities in related fields focused on both basic and applied research at universities, in the institutes of the Academy of Sciences, in the scientific and technological centers (e.g., synchrotrons, ITER, ELI, ESA), and also in the industrial sphere and public administration.

## *Recommended plan of the study*

A pre-requisite of the study in this program is knowledge of plasma physics, surface physics and solid state physics on the Bachelor level.

### *Compulsory courses*

| Code | Subject | Credits | Winter | Summer |
|---|---|---|---|---|
| ***First year of he Master study*** | | | | |
| NEVF122 | **Plasma Physics** | 5 | 2/1 C+Ex | — |
| NEVF129 | **Surface Physics** | 5 | 2/1 C+Ex | — |
| NEVF191 | **Workshop I** | 2 | 0/2 C | — |

| | | | | |
|---|---|---|---|---|
| NEVF151 | **Diploma Thesis Seminar for Students of Surface and Plasma Physics I** | 3 | 0/2 C | — |
| NEVF154 | **Diploma Thesis Seminar for Students of Surface and Plasma Physics II** | 3 | — | 0/2 C |
| NSZZ023 | **Diploma Thesis I** | 6 | 0/4 C | 0/4 C |

***Second year of the Master study***

| | | | | |
|---|---|---|---|---|
| NEVF192 | **Workshop II** | 2 | 0/2 C | — |
| NEVF152 | **Diploma Thesis Seminar for Students of Surface and Plasma Physics III** | 1 | 0/1 C | — |
| NEVF153 | **Diploma Thesis Seminar for Students of Surface and Plasma Physics IV** | 1 | — | 0/1 C |
| NSZZ024 | **Diploma Thesis II** | 9 | 0/6 C | 0/6 C |
| NSZZ025 | **Diploma Thesis III** | 15 | 0/10 C | 0/10 C |

***Compulsory-optional and recommended optional courses***

**Thematic areas corresponding to the final state exam areas**

It is assumed that students enroll in optional courses from at least three thematic areas, from which they will later pass the state final exam. In the particular areas, there are also listed further recommended optional courses (written in *italics*), the completion of which is not necessary for the state final examination. The student needs to obtain at least 55 credits for the courses from these optional courses.

| Code | Subject | Credits | Winter | Summer |
|---|---|---|---|---|
| ***Plasma physics*** | | | | |
| NEVF120 | Advanced Plasma Physics | 7 | — | 2/2 C+Ex |
| NEVF121 | Hot Plasma, Fusion | 3 | 2/0 Ex | — |
| NEVF149 | Elementary Processes and Reactions in Plasma | 5 | — | 2/1 C+Ex |
| ***Plasma processes and their diagnostics*** | | | | |
| NEVF123 | Quantum Electronics and Optoelectronics | 5 | 2/1 C+Ex | — |
| NEVF162 | Optical Spectroscopy of Plasma | 5 | 2/1 C+Ex | — |
| NEVF130 | Selected Topics on Physical Chemistry | 5 | — | 2/1 C+Ex |
| ***Space physics*** | | | | |
| NEVF145 | Space Plasma | 5 | — | 2/1 C+Ex |
| NEVF117 | Plasma Waves | 5 | 2/1 C+Ex | — |
| NEVF173 | Diagnostics in Space Plasmas | 5 | 2/1 C+Ex | — |
| ***Physics of surfaces and thin films*** | | | | |
| NEVF170 | Physical Electronics of Surfaces | 5 | — | 2/1 C+Ex |

| | | | | |
|---|---|---|---|---|
| NEVF114 | Physics of Thin Films | 5 | 2/1 C+Ex | — |
| NEVF134 | Adsorption on Solids | 5 | — | 2/1 C+Ex |
| NEVF109 | *Selected Parts from Physics of Thin Films* | 3 | — | 2/0 Ex |
| NEVF163 | *Selected Chapters from Nanoelectronics* | 3 | 2/0 Ex | — |

***Structure and morphology of surfaces and thin films***

| | | | | |
|---|---|---|---|---|
| NEVF103 | Thin Film Techniques | 5 | — | 2/1 C+Ex |
| NEVF106 | Microscopy of Surfaces and Thin Films | 5 | 2/1 C+Ex | — |
| NEVF136 | Surface Structure and Electron Diffraction | 5 | 2/1 C+Ex | — |
| NEVF172 | *Nanomaterials and Their Properties* | 3 | — | 2/0 Ex |

***Physico-chemical properties of surfaces and thin films***

| | | | | |
|---|---|---|---|---|
| NEVF113 | Electron Spectroscopies | 5 | — | 2/1 C+Ex |
| NEVF168 | Ion and Vibrational Spectroscopy | 5 | 2/1 C+Ex | — |
| NEVF171 | Operando Methods | 5 | 2/1 C+Ex | — |
| NEVF108 | *Advanced Methods in Surface Physics* | 3 | 2/0 Ex | — |
| NEVF148 | *Molecular and Ion Spectroscopy* | 3 | 2/0 Ex | — |
| NEVF167 | *Interfacial Electrochemistry* | 3 | — | 2/0 Ex |

***Vacuum physics***

| | | | | |
|---|---|---|---|---|
| NEVF126 | Vacuum Physics | 5 | 2/1 C+Ex | — |
| NEVF105 | Vacuum Technology | 5 | — | 2/1 C+Ex |
| NEVF125 | Mass Spectrometry | 5 | 2/1 C+Ex | — |

***Experiment automation and data acquisition***

| | | | | |
|---|---|---|---|---|
| NEVF115 | Electronics for Physicists | 5 | 2/1 C+Ex | — |
| NEVF127 | Experiment Automation I | 5 | — | 2/1 C+Ex |
| NEVF144 | High Frequency Electrical Engineering in Physics | 5 | 2/1 C+Ex | — |
| NEVF128 | *Experiment Automation II* | 3 | 2/0 Ex | — |
| NEVF116 | *Applied Electronics* | 5 | — | 2/1 C+Ex |

***Computer physics***

| | | | | |
|---|---|---|---|---|
| NEVF141 | Fundamentals of Computational Physics I | 7 | 2/2 C+Ex | — |
| NEVF138 | Fundamentals of Computational Physics II | 3 | — | 2/0 Ex |
| NEVF160 | Modern Computational Physics I | 5 | 2/1 MC | — |
| NEVF161 | *Modern Computational Physics II* | 5 | — | 2/1 MC |

***Further recommended optional courses***

| Code | Subject | Credits | Winter | Summer |
|---|---|---|---|---|
| NEVF135 | *Programming in IDL — Data Processing and Visualisation* | 3 | 1/1 MC | — |
| NEVF143 | *Statistics and Information Theory* | 3 | 2/0 Ex | — |
| NEVF107 | *C++ for Physicists* | 3 | — | 1/1 MC |
| NEVF111 | *Fortran 90/95 for Physicists* | 3 | — | 1/1 MC |
| NEVF150 | *Fluctuations in Physical Systems* | 3 | — | 2/0 Ex |

***Conditions that must be satisfied to register for the state final exam***

– gain of at least 120 credits
– passing all compulsory courses
– gain of 55 credits from the optional courses,
– submission of the completed diploma thesis within the given deadline

***State final exam***

The student will receive one question from a common basis (part A), i.e., from thematic areas 1 to 3, and three questions from a narrower optional focus (part B), i.e., from thematic areas 4 to 12 according to the chosen focus.

***A Common basis***

*1 Solid state physics*

Crystallography and structure of solids. Types of bonds, structure of elements and simple compounds, x-ray diffraction. Crystal lattice vibrations, optical and acoustic phonons, interaction with electromagnetic radiation. The Sommerfeld model of a metal, electron gas, density of states, Fermi energy. Electronic structure of solids, band theory, charge carriers mobility in solids. Intrinsic and doped semiconductors, P-N junction, photoelectric properties of semiconductors.

*2 Physics of ionized media*

Basics of kinetic theory of gases. Motion of charged particles in electromagnetic fields. Description of plasma, basic concepts and types of plasma. Kinetic description of plasma. Transport processes in plasma. Fluid description of plasma.

*3 Fundamentals of plasma, surface, and thin film physics*

Surface morphology, crystallographic and electronic structure of surfaces. Interaction of radiation and particles with solid surfaces. Experimental methods of surface and thin film physics — diffraction, photoemission, and near field techniques. Gas discharges. Collisional and elementary processes. Plasma diagnostics.

***B Optional focus:***

The student chooses three thematic areas in advance.

*4 Plasma physics*

Collective behavior of plasma. Transport phenomena in plasma. Advanced plasma discharges. Plasma light sources. Magnetohydrodynamic description of plasma and MHD instabilities. Conditions for nuclear fusion in hot plasma, inertial confinement fusion. Magnetic confinement of hot plasma. Hot plasma diagnostics. Chemical kinetics in plasma. Ion–molecule reactions and the influence of molecular excitation.

Experimental techniques for the study of elementary plasma processes. Elementary plasma processes — recombination, relaxation processes, plasma surface interaction.

*5 Plasma processes and their diagnostics*

Fundamentals of quantum electronics, population inversion, stimulated emission. Microwave quantum generators and amplifiers. Types of lasers and their properties. Laser applications, optical communications. Basic concepts of absorption and emission spectroscopy. Spectra of atoms and molecules. Spectroscopy techniques — absorption and emission. Evaluation of plasma parameters from measured spectra. Molecular structure and chemical bond. Determination of molecular structure. Chemical reactions, chemical kinetics and dynamics. Experimental techniques of physical chemistry.

*6 Space physics*

Sun, solar wind, interplanetary magnetic field. Interaction of the solar wind with obstacles. Magnetosphere and ionosphere. Reconnection of magnetic fields, geomagnetic activity. Dispersion relation of waves in plasma. Polarization of waves in magnetized plasma. Whistler modes in space plasma. Radio emissions in space plasma. Measurements of plasma parameters and distribution functions of electrons, protons and heavier ions. Methods of mass spectrum determination, particle detectors, space dust detection. Spacecraft measurements of electric and magnetic fields, spacecraft potential. Ground measurements for the study of processes in the ionosphere and magnetosphere, geomagnetic indices.

*7 Physics of surfaces and thin films*

Electronic structure of surfaces, surface states, band bending. Emission of electrons, work function. Interaction of radiation and particles with solids (excitation, scattering). Phenomena at solid state interfaces. Thin film growth modes and growth phases, elementary processes during deposition. Ad-atom diffusion, nucleation, role of step edges in thin film growth. Rate equations for description of thin film growth. Amorphous, polycrystalline and epitaxial films. Strain in heteroepitaxial growth — Stranski–Krastanov growth mode. Adsorption of molecules on surfaces, the interaction of gas molecules with surfaces, the potential theory of adsorption. Kinetics and dynamics of adsorption and desorption, adsorption isotherms. Experimental methods based on the interaction of gas molecules with surfaces (MB, TPD/TPR, BET). Reactions on solid surfaces, reaction mechanisms, reaction kinetics and dynamics.

*8 Structure and morphology of surfaces and thin films*

Vacuum evaporation. Sputtering of thin films. Measurement of deposition rate and thickness of thin films. Ion etching, lithography. Electron microscopy and contrast in various imaging modes. Microscopic techniques with atomic resolution. Electronic structure of surfaces and tunneling spectroscopy. Near field scanning probe microscopies (STM, AFM, SNOM). Structure and description of ideal surface. Crystallographic structure of surface — relaxation, reconstruction, ideal and real surface. Diffraction theory (geometric and kinematic). Electron diffraction methods.

*9 Physico-chemical properties of surfaces and thin films*

Electron spectroscopies, overview, experimental requirements and equipment (sources, analysers, detectors). Photoelectron spectroscopy. Auger electron spectroscopy. Electron energy loss spectroscopy. Vibrational and rotational states of molecules, theory, vibrational modes. (Ro-)vibrational spectroscopic methods — IR and Raman spectroscopy. Interaction of ions with solid surface. Ion spectroscopy surface methods (LEIS, SIMS). Basics of operando methods and their overview (experimental arrangement, advantages and limitations, application examples). Operando spectroscopies. Operando microscopies. Application of operando methods in heterogeneous catalysis.

*10 Vacuum physics*

Transfer phenomena at low pressures. Real gases, vapour pressure, evaporation and condensation. Interaction of gas with solid on its surface and in volume. Gas flow, flow regimes, vacuum conductivity. Vacuum system and its parameters, theory of pumping process. Physical principles of methods of obtaining low pressures. Physical principles of low pressure measurement, total and partial pressure. Vacuum measuring methods. Principles of mass analysers. Ionization techniques, electron ionization. Ion detection methods. Interpretation of spectra, qualitative and quantitative analysis.

*11 Experiment automation and data acquisition*

Analysis of DC and AC electrical circuits with linear elements. Operational amplifiers, properties and basic applications. Basics of analog signal processing, filtering, noise suppression. Voltage and current sources. Data acquisition and physical experiment control, physical quantities measurement - sensors and actuators. Methods and properties of A-D and D-A conversion. Digital signal processing, application of microprocessors. Basics of process control, dynamic characteristics of a control loop, PI and PID controllers. Circuits at very high frequencies, skin effect and internal impedance. Parameters of a long homogeneous line. Waveguides and resonators. Generation of high frequency power.

*12 Computer physics*

Numerical methods in computer science, root finding, minimization, integration. Molecular dynamics, motion in external force fields, many-body problems. Stochastic methods in computational physics, generation and characterization of random variables. Continuum and hybrid models, comparison with particle models. Solution of ordinary differential equations, order of accuracy, stability, round-off error. Solution of systems of linear equations and partial differential equations. Integral transforms in computer science, fast Fourier transform. Finite element method. Evolutionary programming, encoding, fitness, operators, evolutionary algorithm. Genetic algorithm and genetic programming, crossover, NP problems, syntax trees. Efficient computation of forces in many-body problems. Collision modeling.