Department of Physics

tu dortmund university

Module handbook for the study program

# Master of Science
# Medical Physics and Physics of Living Systems
# (MMP-PLS)

## of TU Dortmund University

**Version: 20.10.2025**

# Contents

# General remarks

**Responsible Person**
As is common in most physics departments and faculties, required courses and major electives rotate among instructors; therefore, module descriptions do not include instructor names but responsible Persons.

**Work Load**
The work load of one credit point corresponds to 30 hours of work. The work load quoted in the description of the modules below represents the typical work load associated with the modules.

**Mode of delivery**
All courses are planned to be delivered face-to-face, but the mode of delivery can be changed in agreement with the students or external constraints. While distance learning is possible for most lectures and seminars, it is difficult to maintain for laboratory courses.

**Examinations**
Most modules are completed by an examination. If the type of examination is not fixed in the module description it has to be specified by the examiner no later than two weeks after the start of the course. Details about the examinations, e.g. the length and the announcement procedure, are detailed in §9 of the Master's Examination Regulation.

**Teaching methods**
The teaching methods used depend on the type of course:

- "Lecture" (L)for lecture-type courses and seminars given by invited speakers
- "Problem-based learning" (T) for tutorials/exercise sessions, e.g. in theoretical physics
- "Seminar" (S) for presentations prepared by students
- "Directed discussion" for an in-class discussion of the presented material organized by the teacher
- "Laboratory method" (P) for lab experiments conducted by the students and under supervision
- "Research" for the Master thesis and internships

Teachers can deviate from the teaching methods indicated given personal preferences

# Description of the study program

The Master of Science in Medical Physics and Physics of Living Systems program has a standard period of study of 4 semesters and a total number of 120 credit points (CP). It is divided into a study phase (1st - 3rd semester) with 75 CP and a research phase (3rd - 4th semester) with 45 CP.

The program offers two tracks, from which one has to be chosen:

Track A: Medical Physics

Track B: Physics of Living Systems

Each Track combines a number of mandatory courses (core curriculum) as well as electives. While the core curriculum assures a high standard in order to pass the program, a wide range of electives enables the students to match their individual interests in this fast-growing field.

All students are divided into one of three study pathways according to their previous training in medical physics before starting the Master programme. To align students' basic knowledge of medical physics, there are “synchronisation courses”, which are credited in the elective area.

# Study Phase

During the study phase, modules from four different areas must be taken.

1. Synchronisation (9 CP)

Students are assigned to one of three course plans (1, 2, 3) based on their subject-specific prior knowledge (i.e., their Bachelor’s degree). A synchronisation course is assigned to each of these course plans. For students assigned to course plan 2 or 3, the synchronisation course is compulsory. For students assigned to the course plan 1, the synchronisation course is optional and they can choose elective courses instead to reach their full CPs.

| Plan | Bachelor’s degree | Synchronisation course | CP |
|---|---|---|---|
| 1 | Medical Physics | *Free electives* | 9 |
| 2 | Physics | Biomedical Physics | 9 |
| 3 | Biomedical Engineering, Biophysics or related subjects | Theoretical Physics | 9 |

Exception: If the assigned synchronisation course has been successfully attended within the Bachelor’s program, students have to choose elective courses instead to reach their full CPs.

2. Fundamentals of thermodynamics and statistics (Mandatory) (13/14 CP)

Within the Fundamentals of thermodynamics and statistics the students need to select courses in statistics and thermodynamics. Students have to choose one of the following two courses:

| Modules | CP |
|---|---|
| Wahrscheinlichkeitsrechnung und mathematische Statistik (German) | 4 |
| Statistical methods of data analysis A (English) | 5 |

As well as one of the courses thermodynamics/statistical physics:

| **Modules** | **CP** |
|---|---|
| Thermodynamik und Statistik (German) | 9 |
| Thermodynamics and Statistical Physics (RUB, English) | 9 |

Exception: If any of the courses has been successfully attended within the Bachelor's program, students have to choose elective courses instead to reach their full CPs.

3. Area of specialization (39 CP)

In the master of Medical Physics and Physics of Living Systems, a specialisation track must be taken:

| **Track** | **CP** |
|---|---|
| A) Medical Physics | 39 |
| B) Physics of Living Systems | 39 |

The module representatives are:

| **Track** | **Module representative** |
|---|---|
| A) Medical Physics | Jun.-Prof. Dr. Armin Lühr |
| B) Physics of Living Systems | Prof. Dr. Matthias Schneider |

4. Free electives (13-14 CP)

Free electives can be chosen from a large selection of courses. Students can explore their interest within both possible tracks, i.e., every course that is part of a specialisation track can also be chosen as a free elective. Additionally, a variety of modules with different topics is provided. An overview of courses can be found below. The division into subject areas is for clarity purposes only.

# Research Phase

In the 3rd and 4th semester, the focus shifts to research. Parallel to remaining courses in the 3rd semester, there is a research internship to prepare for the Master's thesis. The 4th semester is dedicated to the Master's thesis.

| **Module** | **CP** |
|---|---|
| Research internship for the Master's thesis | 15 |
| Master's thesis and presentation | 30 |
| ***Sum*** | 45 |

# Typical Course Timelines (Examples)

*Table 1: Example for students with a* ***B. Sc. in Medical Physics*** *(**NO** Synchronisation Course) studying* ***Track A Medical Physics***

| | Semester | Fundamentals of Thermo-dynamics and statistics | Track A: Medical Physics | Electives/ Synchroni-sation courses | Master‘s thesis | Total |
|---|---|---|---|---|---|---|
| | | | | | | |
| Study Phase | **1** | | Advanced Clinical Medical Physics 6 CP | Radiation Applications in the Clinic 3 CP | | 29 CP |
| | | | Advanced Medical Imaging 6 CP | Ultrasound in Medicine 5 CP | | |
| | | | AI for Medical Applications 9 CP | | | |
| | | | | | | |
| | **2** | Statistical Methods of Data Analysis A 5 CP | Medical Physics and Technology in Particle Therapy 3 CP | Methods of Clinical Research 5 CP | | 31 CP |
| | | Thermo-dynamics and Statistical Physics 9 CP | Advanced Magnetic Resonance Imaging 6 CP | | | |
| | | | Fundamentals of Detector Physics 3 CP | | | |
| | | | | | | |
| Research Phase | **3** | | TPS – Practical Course on Treatment Planning 6 CP | Applications of Machine Learning in Medical Physics 3 CP | Research Internship 15 CP | 30 CP |
| | | | | Physics of Life 6 CP | | |
| | | | | | | |
| | **4** | | | | Master’s thesis 30 CP | 30 CP |
| | | | | | | |
| | **Sum:** | 14 CP | 39 CP | 22 CP | 45 CP | 120 CP |

*Table 2: Example for students with a **B. Sc. in Medical Physics** studying **Track A Medical Physics**.*

| | Semester | Fundamentals of Thermo-dynamics and statistics | Track A: Medical Physics | Electives/ Synchroni-sation courses | Master's thesis | Total |
|---|---|---|---|---|---|---|
| | | | | | | |
| Study Phase | 1 | | Advanced Clinical Medical Physics 6 CP | Modern Radiotherapy 6 CP | | 33 CP |
| | | | Advanced Medical Imaging 6 CP | Physics of life 6 CP | | |
| | | | AI for Medical Applications 9 CP | | | |
| | | | | | | |
| | 2 | Statistical Methods of Data Analysis A 5 CP | Applied Proton Therapy 6 CP | Computational Physics 9 CP | | 30 CP |
| | | Thermo-dynamics and Statistical Physics 9 CP | | Basic radiation protection regulation for medical physics experts 1 CP | | |
| | | | | | | |
| | | | | | | |
| Research Phase | 3 | | Radiation Applications in the Clinic 3 CP | | Research Internship 15 CP | 27 CP |
| | | | TPS – Internship for radiation planning 6 CP | | | |
| | | | Applications of Machine Learning in Medical Physics 3 CP | | | |
| | | | | | | |
| | 4 | | | | Master's thesis 30 CP | 30 CP |
| | | | | | | |
| | **Sum:** | 14 CP | 39 CP | 22 CP | 45 CP | 120 CP |

*Table 3: Example for students with a* ***B. Sc. in Biomedical Engineering*** *(Synchronisation Course* ***Theoretical Physics*** *(WS)) studying* ***Track A Medical Physics****.*

| | Semester | Fundamentals of Thermo-dynamics and statistics | Track A: Medical Physics | Electives/ Synchroni-sation courses | Master's thesis | Total |
|---|---|---|---|---|---|---|
| | | | | | | |
| Study Phase | 1 | | Advanced Clinical Medical Physics 6 CP | **Synch. Course** Theoretical Physics 9 CP | | 29 CP |
| | | | Advanced Medical Imaging 6 CP | Ultrasound in Medicine 5 CP | | |
| | | | | Applied Physics in Clinical Medicine 3 CP | | |
| | | | | | | |
| | 2 | Statistical Methods of Data Analysis A 5 CP | Advanced Magnetic Resonance Imaging 6 CP | Methods of Clinical Research 5 CP | | 31 CP |
| | | Thermo-dynamics and Statistical Physics 9 CP | Applied Proton Therapy 6 CP | | | |
| | | | | | | |
| | | | | | | |
| Research Phase | 3 | | Radiation Applications in the Clinic 3 CP | | Research Internship 15 CP | 30 CP |
| | | | AI for Medical Applications 9 CP | | | |
| | | | Applied Dosimetry 3 CP | | | |
| | | | | | | |
| | 4 | | | | Master's thesis 30 CP | 30 CP |
| | | | | | | |
| | **Sum:** | 14 CP | 39 CP | 22 CP | 45 CP | 120 CP |

*Table 4: Example for students with a **B. Sc. in Physics** (Synchronisation Course **Biomedical Physics** (WS)) studying **Track B Physics of Living Systems**.*

| | Semester | Fundamentals of Thermo-dynamics and Statistics | Track B: Physics of Living Systems | Electives/ Synchroni-sation courses | Master's thesis | Total CP |
|---|---|---|---|---|---|---|
| | | | | | | |
| Study Phase | 1 | | Physics of Life 6 CP | **Synch. Course** Biomedical physics 9 CP | | 30 CP |
| | | | AI for Medical Applications 9 CP | Advanced Medical Imaging 6 CP | | |
| | 2 | Thermodynamic and Statistical Physics 9 CP | Lab PLS 5 CP | | | 29 CP |
| | | Statistical methods of data analysis A 5 CP | Tissue Engineering 4 CP | | | |
| | | | Soft Matter 6 CP | | | |
| Research Phase | 3 | | MD – Soft Matter and Biomaterials 6CP | Current Topics in Cell Biology 4 CP | Research Internship 15 CP | 32 CP |
| | | | Biomaterials 4 CP | Applied Phys in Clinical Med 3 CP | | |
| | | | | | | |
| | | | | | | |
| | 4 | | | | Master's thesis 30 CP | 30 CP |
| | Sum: | 14 CP | 40 CP | 22 CP | 45 CP | 121 CP |

*Table 5: Example for students with a* ***B. Sc. Biomed Eng*** *(Synchronisation Course* ***Theoretical Physics*** *(WS)) studying* ***Track B Physics of Living Systems****.*

| | **Semester** | **Fundamentals of Thermo-dynamics and Statistics** | **Track B: Physics of Living Systems** | **Electives/ Synchroni-sation courses** | **Master's thesis** | **Total CP** |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Study Phase** | **1** | | Physics of Life<br>6 CP | **Synch. Course** Theoretical Physics<br>9 CP | | 30 CP |
| | | | AI for Medical Applications<br>9 CP | Advanced Medical Imaging<br>6 CP | | |
| | **2** | Thermodynamic and Statistical Physics<br>9 CP | Lab PLS<br>5 CP | | | 29 CP |
| | | Statistical methods of data analysis A<br>5 CP | Fundamental Immunology<br>4 CP | | | |
| | | | Soft Matter<br>6 CP | | | |
| **Research Phase** | **3** | | MD – Soft Matter and Biomaterials<br>6CP | Current Topics in Cell Biology<br>4 CP | Research Internship<br>15 CP | 32 CP |
| | | | Biomaterials<br>4 CP | Applied Phys in Clinical Med<br>3 CP | | |
| | | | | | | |
| | | | | | | |
| | **4** | | | | Master's thesis<br>30 CP | 30 CP |
| | **Sum:** | 14 CP | 40 CP | 22 CP | 45 CP | 121 CP |

# Detailed module descriptions

# Synchronisation courses

| **Module:** Biomedical Physics (Synch Course) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. sem. | **Credits**<br>9 | **Work load**<br>270 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | | Tutorial | T | 3 | 2 |
| **2** | **Language: English** | | | | |
| **3** | **Content** | | | | |

I. **Physics of Physiology & Biophysics**

1) History of the Role of Physics in Medicine. How Biology stimulated physics and how physics stimulated biology
2) Thermodynamics: The first and 2nd Law and its statistical interpretation. Diffusion
   Math Section: Probability Theory
3) Energetics and physical chemistry in living systems, chem. Potential and puffer systems; Blood oxygenation (Allostery)
4) Biomolecules and The Cell: From Material to Protein Folding
5) Hydrodynamics of Blood flow, viscosity, FL Effect and Blood Clotting
   Math Section: The Navier Stokes Equation
6) The Heart as a mechanical pump; The heart as a muscle
   Math Section: Elasticity Theory
7) Membranes & Introduction to Neuroscience
8) Physics of hearing; resonance, impedance and non-linear oscillators
   Math Section: The Wave Equation
9) Physics of the eye

**II. Medical Physics: Imaging tools**

1) X-Ray and Computed Tomography (CT)
   Math Section: Fourier Transformation, Convolution
2) Magnetic Resonance Imaging (MRI)
3) Ultrasound
4) EKG and Blood Pressure
5) Modern Tools: Cell Mechanics, Microfluidics, PCR, CTC, DNA-Squeezing, FACS…
6) Tool in challenging Environments: Socioeconomic Considerations

| | | |
|---|---|---|
| **4** | **Learning outcome**<br>After successfully completing the module students<br><br>– recognize the complexity of biological processes and the necessity of having multiple physical concepts ready to understand these processes quantitively.<br>– are able to transform physical principles and knowledge to problems of living systems and medical applications.<br>– can apply physical concepts of elasticity theory in membrane mechanics and the physics of hearing.<br>– can apply the principles of hydrodynamics to understand physical foundation of blood flow and blood clotting. They understand blood as a complex fluid in contrast to "simple" fluids like water and air.<br>– will have an overview of diagnostically relevant tools and their physical principles.<br>– are able to apply mathematical tools to reconstruct an image from x-ray, MRI and ultrasound studies.<br>– are up to date on recent developments in diagnostic tools.<br>– can apply physical concepts to minimize effort, prerequisites and costs of modern medical tools as may (for instance) become necessary in socioeconomic challenged communities. | |
| **5** | **Examination**<br>Graded exam (120 min) or oral exam (30 min), will be announced at the beginning of the course | |
| **6** | **Participation Requirements**<br>No | |
| **7** | **Module type**<br>Elective module/ mandatory module | |
| **8** | **Responsible**<br>Prof. Dr. Matthias Schneider | **Faculty in charge**<br>Department of Physics |

| **Module:** Theoretical Physics (Synch Course) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. sem. | **Credits**<br>9 | **Work load**<br>270 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | | Tutorial | T | 3 | 2 |
| **2** | **Language: English** | | | | |

**3 Content**

**I. Theoretical Mechanics**

1) Elements of classical Newtonian mechanics, conservation laws (momentum, angular momentum energy), 2-body problem with central force
2) Stationary action principle, Lagrangian mechanics, Hamiltonian mechanics
3) Conservation laws, dynamics in phase space, Poisson brackets, overview nonlinear dynamics

**II. Quantum Mechanics**

1) Limits of classical physics
2) 5 postulates, wave functions, operators, uncertainty relation, Hamiltonian, Schrödinger equation, correspondence principle, Ehrenfest theorem
3) Harmonic oscillator, potential well, potential step, tunneling
4) Angular momentum operator, spin, normal Zeeman effect
5) Hydrogen atom
6) Perturbation theory, hyperfine structure, Stark, anomalous Zeeman effect

**4 Learning outcome**

The students are familiar with the principles and laws of classical theoretical mechanics and quantum mechanics as outlined in the course content and can apply them, i.e. they can classify phenomena of physics and microphysics in the context of abstract models and establish connections to the appropriate concepts of mathematics.

**5 Examination**

Study achievements: homework
Graded exam (180 min) or oral exam (30 min), will be announced at the beginning of the course

**6 Participation Requirements**

No

**7 Module type**

Elective module/ mandatory module

| | | |
|---|---|---|
| **8** | **Responsible**<br>Prof. Dr. Jan Kierfeld | **Faculty in charge**<br>Department of Physics |

# Fundamentals of thermodynamics and statistics

| **Module:** Statistical Methods of Data Analysis / SMD A (PHY523a) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:** in SS | **Duration:** 1 semester | **Semester:** 2nd sem. | **Credits** 5 | **Work load** 150 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Exercise | L+T | 5 | 2 + 1 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>**SMD A: From raw data to signal subsurface separation:**<br>Numerical methods of data processing, data handling and programming, algorithms and data structures, methods of linear algebra, probability theory, one and multidimensional distributions, random numbers and Monte Carlo methods, data mining methods: Discriminant Analysis, Principal Component Analysis, Feature Selection, Supervised Learning (kNN, Decision Trees, Random Forests), MRMR, Unsupervised Learning (Ensemble Learner), Convolutional Neural Nets and others. | | | | |
| 4 | **Learning outcome**<br>Today, data are usually collected electronically. The students learn the appropriate handling of statistical methods for the analysis of moderate to very large amounts of data, following the the temporal sequence of a data analysis. The exercises are solved (also) on the computer using current software. In the course, practical competence in data analysis is acquired for the preparation of theses and later professional practice. | | | | |
| 5 | **Examination**<br>Course Credits: Active participation in the exercises of SMD A.<br>Module examination: written or oral. The form of examination will be announced at the beginning of the semester. | | | | |
| 6 | **Participation Requirements**<br>Favorable: Programming knowledge in a suitable language, e.g. Python;<br>Recommended: Participation in the Toolbox Workshop<br>The SMD A event should be heard before the SMD B event. | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. W. Rhode | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Wahrscheinlichkeitsrechnung und mathematische Statistik (Informatik) (**GW02**) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load**<br>120 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Tutorial | L+T | 4 | 4 |
| **2** | **Language:** Deutsch | | | | |
| **3** | **Content**<br>Characteristics and data types, statistical key figures for univariate and bivariate data (location, scatter, connection). Probability spaces and basics of statistical modeling. Random variables and their distributions, important probability distributions. Conditional probabilities and stochastic independence. expected value and variance; Markoff chains. Estimation, statistical tests and confidence intervals | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>– Students understand the basics of statistical modeling<br>– Students can apply the statistical methods presented | | | | |
| **5** | **Examination**<br>Study achievements: homework, module examination: graded exam (max. 120 min) | | | | |
| **6** | **Participation Requirements**<br>No | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Dean of the Faculty of Statistics | | **Faculty in charge**<br>Department of Statistics | | |

| **Module:** Thermodynamik und Statistik (**PHY531**) | | | | |
|---|---|---|---|---|
| **Degree Program: Bachelor Physics (B.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>9 | **Work load**<br>270 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | 2 | Tutorial | T | 3 | 2 |
| **2** | **Language:** deutsch | | | | |
| **3** | **Content**<br><u>Thermodynamics:</u> Thermodynamic systems; extensive and intensive sizes; the main theorems, ideal gas, Carnot process, efficiency, heat engines. Thermodynamic potentials and relations to thermodynamics with variable particle numbers, phase diagrams, phase equilibrium, van der Waals gas, multi-substance systems, law of mass action. Osmotic pressure. Optional: thermodynamics in external fields.<br><u>Statistics:</u> Macroscopic systems, concepts of probability, arguments for a statistical description, density operators for equilibrium ensembles, definition of entropy in statistics, relation to thermodynamics. Microcanonical, canonical, grandcanonical ensembles and their equivalence, fluctuations, occupation number representation with application to the ideal Fermi and Bose gases, creation and annihilation operators, pseudobosons, Planck's radiation law, optional: transition from quantum statistics to classical, applications: classical virial development , magnetic moments, magnetism, molecular field and variation principle, Ising model, Landau theory of phase transitions, critical exponents and scale invariance, Ginzburg-Landau theory, renormalization group, perturbation calculation in quantum statistics, linear response theory, dissipation fluctuation theorem. | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>– Students can recognize, classify and interpret the characteristic phenomena of thermodynamics, as well as master and apply its formal apparatus. The same applies to the statistical underpinnings of thermodynamics.<br>– In particular, students understand that it was only through quantum statistics that the paradoxes and inadequacies of thermodynamics and classical statistics could be overcome<br>– In the exercises, students learned to describe simple physical systems both formally and verbally and to present solutions by solving problems independently and discussing them in groups<br>– Students learned to check their learning success and measure it against that of their fellow students | | | | |
| **5** | **Examination**<br>Study achievements: homework, module examination: graded module exam (180 min) | | | | |
| **6** | **Participation Requirements**<br>No | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Dean of Studies in the Faculty of Physics | **Faculty in charge**<br>Department of Physics | | | |

| **Module:** Thermodynamics and Statistical Physics (RUB) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Physics (M. Sc.), RUB** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>9 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Tutorial | L+T | 6 | 4+2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Quantum statistics and classical statistical mechanics, thermodynamics, applications. Starting point is the simple statistics of many particles, thermodynamics is derived from this. Afterwards quantum statistics with applications | | | | |
| **4** | **Learning outcome**<br>After successfully completing this module, the students<br>– Have a basic understanding of the concepts of statistical mechanics<br>– Know the fundamental concepts of quantum statistics<br>– Are familiar with fundamental definitions of classical and quantum mechanical statistical physics<br>– Can solve typical problems of non-interacting multi-particle physics | | | | |
| **5** | **Examination**<br>Written examination of 120 min | | | | |
| **6** | **Participation Requirements**<br>Formal: None<br>Content: Knowledge of the contents of “Introduction to Quantum Mechanics and Statistics” (Bachelor) will be expected<br>Preparation: None | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. Sulpizi | **Faculty in charge**<br>Department of Physics (RUB) | | | |

# Track A: Medical physics

| **Mandatory courses** | **Sem.** | **CP** |
|---|---|---|
| Advanced Clinical Medical Physics | WS | 6 CP |
| Advanced Medical Imaging | WS | 6 CP |
| AI for Medical Applications | WS | 9 CP |
| | | |
| **Elective courses** | | |
| *Radiotherapy and Dosimetry* | | |
| Radiation applications in the clinic | WS | 3 CP |
| Modern Radiotherapy | WS | 6 CP |
| Medical Physics and Technology in Particle Therapy | SS | 3 CP |
| Applied Proton Therapy | SS | 6 CP |
| TPS – Practical Course on Treatment Planning | WS + SS | 6 CP |
| Basic radiation protection regulation for medical physics experts | SS | 1 CP |
| Fundamentals of Detector Physics | SS | 3 CP |
| Applied Dosimetry | WS | 3 CP |
| | | |
| *Medical Imaging and Machine Learning* | | |
| Advanced Magnetic Resonance Imaging | SS | 6 CP |
| Image Processing in Medicine | SS | 5 CP |
| Ultrasound in Medicine | WS | 5 CP |
| Applications of Machine Learning in Medical Physics | WS | 3 CP |

The following modules are of particular interest with regard to a later career as a clinical medical physics expert:

- Advanced Clinical Medical Physics
- Advanced Medical Imaging
- Radiation applications in the clinic
- Modern Radiotherapy
- Medical Physics and Technology in Particle Therapy
- Applied Proton Therapy
- TPS – Practical Course on Treatment Planning (German)
- Basic radiation protection regulation for medical physics experts (German)
- Applied Dosimetry

# Mandatory courses

| **Module:** Advanced Clinical Medical Physics | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

<table>
<tr><td rowspan="3">1</td><td colspan="5">Module structure</td></tr>
<tr><td>No.</td><td>Element / Course</td><td>Type</td><td>Credits</td><td>Contact hours per week</td></tr>
<tr><td>1</td><td>Lecture</td><td>L</td><td>6</td><td>4</td></tr>
<tr><td>2</td><td colspan="5">Language: English</td></tr>
<tr><td>3</td><td colspan="5">Content<br>Dosimetry and radiation therapy:<br>1) Dosimetry: basic terms and definitions of clinical dosimetry, secondary electron balance, cavity theory, Bragg-Gray theory, detectors, types clinical. Dosimeter, dosimeter for special applications, water absorbed dose concept incl., calorimetric representation, calibration of dosimeters teletherapy and brachytherapy, legal basis for metrological controls, dose measurement method according to DIN 6800-2<br>2) Physics and technology of the electron linear accelerator<br>3) Introduction to the basics of the therapeutic forms of brachytherapy and proton therapy on the eye: Modalities of brachytherapy, therapy indications, target volume localization, therapy planning, therapy implementation, applicators and forms of application, afterloading brachytherapy, intravascular brachytherapy, eye tumor brachytherapy, proton therapy on the eye, research projects in the field of brachytherapy<br>4) Introduction to the basics and implementation of radiotherapy (teletherapy) for tumor patients: Biological basics: types of radiation, dose-effect relationships, cell survival curves, linear-quadratic model, fractionation. Radiation therapy treatment chain: patient positioning and immobilization, 3D imaging as the basis for radiation planning, concept of contouring of target volumes and organs at risk, radiation planning (choice of technique, dose calculation, plan assessment), patient positioning on the device, verification procedures. Conformational radiotherapy: requirements, possibilities, limits. Intensity-modulated radiation therapy as a modern development: Inverse radiation planning, method for implementing intensity-modulated techniques on conventional linear accelerators. Helical tumor therapy as an alternative concept. Dosimetric verification of intensity-modulated irradiations. Approaches to improve the accuracy of beam application: Stereotactic radiation therapy. Image-guided radiation therapy. Problems and possible solutions in the irradiation of respiratory tumors. Practical demonstration at the University Hospital Essen: Implementation of image-guided, intensity-modulated radiation therapy on the phantom.<br>5) Quality assurance in radiotherapy<br><br>Imaging procedures and radiation protection:<br>6)X-ray imaging: Generation and absorption of X-rays, image formation, detectors and films, applications of X-ray imaging, e.g. DEXA, mammography, classic X-ray image<br>7) Tomographic methods CT, PET, SPECT: Functional principle, technical basics, combination devices, radiation detectors, image acquisition and reconstruction, basics of contrast agent application, basics for the comparability and quantification of CT examinations based on HU values, quantification methods (PET), Production, use and effects of radiopharmaceuticals,<br>8) Radiation protection: How can patients and staff be protected from the ionizing radiation from imaging procedures? The dose exposures of the various imaging procedures are presented.</td></tr>
<tr><td>4</td><td colspan="5">Learning outcome<br>After successfully completing the module, students will have acquired knowledge in the field of radiation therapy and imaging, which is typically one of the requirements for medical physics experts.<br>The students<br>1. are familiar with the basics of dosimetry and its applications,<br>2. have acquired in-depth knowledge of the physical and technical fundamentals of radiation therapy and the functional principles of imaging techniques,<br>3. know the advantages and disadvantages and the technical limitations of teletherapy and brachytherapy and imaging methods,<br>4. are familiar with the biological and technical requirements as well as the process of treatment with ionizing radiation and the physical principles of imaging procedures using ionizing radiation.<br>5. understand the connections between ionizing radiation. Radiation protection, diagnostic methods, dosimetry, biological effectiveness of ionizing radiation and radiation therapy.</td></tr>
</table>

| | | |
|---|---|---|
| **5** | **Examination**<br>will be announced at the beginning of the course | |
| **6** | **Participation Requirements**<br>Basic knowledge of radiation physics and the interaction of radiation and matter is required. These can be acquired, for example, by successfully participating in the “Strahlungsphysik I” module of the bachelor’s degree program in Medical Physics at TU Dortmund University. | |
| **7** | **Module type**<br>Elective module/ mandatory module | |
| **8** | **Responsible**<br>Prof. Dr. Andreas Block (Klinikum Dortmund) | **Faculty in charge**<br>Department of Physics |

| **Module:** Advanced Medical Imaging | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Tutorial | L+T | 6 | 4 |
| 2 | **Language: English** | | | | |
| 3 | **Content**<br>The “Advanced Medical Imaging” module provides students with advanced concepts, technologies and applications of medical imaging. It covers a wide range of imaging techniques used in modern clinical diagnostics and research. The focus is on the theoretical foundations of image processing, the functioning of the various imaging procedures, including the meaning and clinical relevance of the imaged quantities, their clinical application and their current limitations.<br><br>The module will cover the following key topics:<br>• Introduction to imaging technologies: Historical development and current technologies.<br>• Basics of image processing: image quality, filtering, noise reduction, reconstruction.<br>• Imaging techniques and their clinical relevance:<br>  o Magnetic resonance imaging (MRI) and functional MRI<br>  o Computed tomography (CT)<br>  o Positron emission tomography (PET) and single photon emission tomography (SPECT)<br>  o Ultrasound (US) and optical imaging (OI)<br>  o Hybrid imaging techniques (e.g. PET/CT, PET/MRI)<br>• Image analysis and interpretation: quantitative analysis, image segmentation and registration and 3D modeling.<br>• Clinical applications: Tumor diagnostics, cardiology, neurology, radiology, minimally invasive surgery.<br>• Future of medical imaging: artificial intelligent (AI) and machine learning in image processing, new imaging techniques and their potential applications. | | | | |
| 4 | **Learning outcome**<br>Upon successful completion of this module, students will be able to:<br>• Explain the principles and technologies behind advanced medical imaging techniques.<br>• Compare the advantages and limitations of imaging modalities such as MRI, CT, PET, SPECT, US, and OI.<br>• Apply image processing and analysis techniques to interpret medical images and assist in clinical decision-making.<br>• Understand the role of imaging in personalized medicine and clinical research.<br>• Discuss current trends and future directions in medical imaging, including the use of AI and machine learning. | | | | |
| 5 | **Examination**<br>Will be announced at the beginning of the course | | | | |
| 6 | **Participation Requirements**<br>Basic knowledge on physics and technology of medical imaging as provided by the courses "Medical Physics II" or "Biomedical Physics (Synch Course)" is desirable, but not mandatory for understanding the topics in this course. | | | | |
| 7 | **Module type**<br>Elective module/ mandatory module | | | | |
| 8 | **Responsible**<br>Jun.-Prof. A. Lühr<br>PD Dr. habil rer. nat. Mona Salehi Ravesh | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** AI for Medical Applications | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>9 | **Work load**<br>270 h |

<table>
<tr><td rowspan="3">1</td><td colspan="5">Module structure</td></tr>
<tr><td>No.</td><td>Element / Course</td><td>Type</td><td>Credits</td><td>Contact hours per week</td></tr>
<tr><td>1</td><td>Lecture (2h) + Tutorial (4h)</td><td>L+T</td><td>9</td><td>6</td></tr>
<tr><td>2</td><td colspan="5">Language: English</td></tr>
<tr><td>3</td><td colspan="5">Content<br>• Motivation – What are the goals and what tools are required to attain them?<br>• Medical Data – Types, Standards & Multimodality<br>• Machine Learning Basics I & II<br>• Basic and advances Computer Vision with Deep Learning. What does the computer see?<br>• Natural Language Processing – From Basics to Large Language models. How does the computer read?<br>• Introduction to Generative AI – GAN and Diffusion models<br>• Timeseries Analysis with classical methods and AI<br>• Introduction to AI Agents<br>• What else is there? Pointers to other methods and bleeding edge developments.<br><br>Exercises accompanying the lecture content. The algorithms and approaches are implemented and evaluated using real medical data sets. Students will have access to a learning platform with GPUs to train their models.</td></tr>
<tr><td>4</td><td colspan="5">Learning outcome<br>• Participants will be able to assess the importance of AI in medicine<br>• Know about types of medical data and how to handle it<br>• Understand how to apply classic machine learning and AI algorithms to medical images and clinical text<br>• After the course, participants will be able to familiarize themselves independently with more advanced AI procedures and apply (i.e. programming) them to the medical domain</td></tr>
<tr><td>5</td><td colspan="5">Examination<br>Graded exam (90 min) or oral exam (30 min), will be announced at the beginning of the course</td></tr>
<tr><td>6</td><td colspan="5">Participation Requirements<br>• Solid programming skills in Python or similar language<br>• Experience with git, ssh and command line tools desirable</td></tr>
<tr><td>7</td><td colspan="5">Module type<br>Mandatory module</td></tr>
<tr><td>8</td><td colspan="2">Responsible<br>Prof. Dr. Dr. Jens Kleesiek,<br>Prof. Dr. Michael Kamp</td><td colspan="3">Faculty in charge<br>Medical Faculty UDE / Department of Physics</td></tr>
</table>

# Elective courses

| **Module:** Radiation applications in the clinic | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | Single appointments + block course |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Basics, clinical applications and current developments in research in the areas of radiation therapy, nuclear medicine, radiology and medical radiation protection. An overarching focus topic is determined for each seminar series. Possible topics include, for example, the biological effects of radiation, physical measurement methods in clinical environments or current treatment and diagnostic options and their limitations. In addition to technical aspects of the methods, their relevance and requirements in the clinical environment should also be discussed. | | | | |
| 4 | **Learning outcome**<br>By completing the module, students have acquired in-depth knowledge of clinical aspects of medical physics that are used in the areas of radiation therapy, nuclear medicine, radiology and medical radiation protection.<br>You can identify the basic physical principles of diagnostic and therapeutic methods and understand their interaction as well as practical limitations in applying the principles due to the complex patient situation.<br>You are able to familiarize yourself with a complex subject area independently and present the essential content in an understandable and convincing manner. You have knowledge of modern presentation techniques and can use them.<br>They can defend their point of view in a scientific discussion. | | | | |
| 5 | **Examination**<br>Provision of academic achievement. The coursework is achieved in the form of a lecture and participation in the discussion of other lectures. | | | | |
| 6 | **Participation requirements**<br>Basic knowledge of medical physics and radiation physics is required. These can be acquired, for example, by successfully participating in the “Medizinphysik II” or “Strahlungsphysik I” module of the bachelor's degree program in Medical Physics at the TU Dortmund. | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Jun.-Prof. Dr. Armin Lühr (TUDo) | | **Faculty in charge**<br>Department of Physics | | |
| 9 | **Teachers**<br>Jun.-Prof. Dr. Armin Lühr (TUDo), Prof. Dr. Andreas Block and Dr. Katharina Loot (Klinikum Dortmund) | | | | |

| **Module:** Modern Radiotherapy | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Tutorial | L+T | 6 | 4 |
| 2 | **Language: English** | | | | |
| 3 | **Content**<br>Radiotherapy is multifaceted, and the complexity of tumor treatment requires the use of different radiotherapy modalities and technical solutions to achieve optimal treatment results. The lecture provides an introduction to modern radiotherapy:<br>- Imaging procedures in radiotherapy (repetition)<br>- Structure recognition, segmentation and registration in radiotherapy<br>- State of the art of photon therapy<br>- Stereotaxy and radiosurgery<br>- Radiotherapy with charged particles<br>- Temporal-spatial fractionation in radiotherapy<br>- FLASH therapy<br>- 4D radiotherapy (for mobile tumors)<br>- Adaptive radiotherapy<br>- MRI-based radiotherapy<br>- Boron neutron capture therapy<br>- Brachytherapy and intraoperative radiotherapy<br>- Radiotherapy for pregnant patients | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module, students can:<br>- Describe and differentiate the various modern radiation techniques such as Intensity Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), helical tomotherapy, sterotaxy, image-guided radiation therapy (IGRT), adaptive radiation therapy, charged particle therapy and brachytherapy for optimal cancer treatment and for different tumor types.<br>- Differentiate the conceptual applications of imaging techniques and in vivo dosimetry procedures in modern radiation techniques.<br>- Evaluate the risk of secondary tumors after radiotherapy. | | | | |
| 5 | **Examination**<br>Course credits: active participation<br>Module examination: oral examination or written examination | | | | |
| 6 | **Participation Requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dr. A. Hammi | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Medical physics and technology of particle therapy | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>Radiation effect of higher-energy protons and other nuclei, radiobiological effect, beam generation by cyclotron or synchrotron, Bragg peak, range calculation, spread out Bragg peak, functional principle and design of the systems with gantry and radiator head, different beam types and corresponding radiator heads for proton therapy, radiation planning: concepts and clinical case studies | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module, students will be able to understand and categorize the basics and applications of particle therapy. They know the difference in lateral and depth dose profiles due to the completely different nature of interactions in tissue between photons and particles (protons). You are familiar with the various beam generation techniques. In addition, they understand the methods for beam expansion and depth modulation. You can name the essential elements of the complex irradiation systems and explain their function. They can apply the principles of appropriate biological and physical radiation treatment planning. | | | | |
| **5** | **Examination**<br>will be announced at the beginning of the course | | | | |
| **6** | **Participation Requirements**<br>Basic knowledge of radiation physics and the interaction of radiation and matter is required. These can be acquired, for example, by successfully participating in the “Strahlungsphysik I” module of the bachelor’s degree program in Medical Physics at TU Dortmund University. | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | | **Faculty in charge**<br>Department of Physics | |
| **9** | **Teacher**<br>Dr. C. Bäumer (WPE) | | | | |

| **Module:** Applied Proton Therapy | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

**1 Module structure**

| No. | Element / Course | Type | Credits | Contact hours per week |
|---|---|---|---|---|
| 1 | Computer Lab | P | 6 | 4 |

**2 Language:** English

**3 Content**

Basics of the Monte Carlo simulation method

- Interaction of ionizing radiation and description by means of computer simulations
- Focus: Proton radiation and field shaping for clinical applications in radiation therapy
- Simulation of patient irradiation by integration of CT image data sets
- other changing topics: e.g. radiation protection or biological effectiveness

In each course, a compact introduction to the topic is followed by its direct implementation in simulations to be created by the students themselves. In a final project work, a complete irradiation is simulated and evaluated from a clinical point of view.

**4 Learning outcome**

After successful completion of the module, students can

- Name the basics of Monte Carlo (MC) simulation techniques and apply them to specific problems involving ionizing radiation.
- Interpret and process results from simulations and present them in an appropriate manner.
- Explain the effect of individual components of different beam shaping techniques for clinical treatment fields and recreate them using computer simulations.
- Recognize and explain differences in the physical dose distribution of various types of radiation and irradiation techniques.
- Explain the data structure of the clinical standard file format (DICOM) and display, read and process content in suitable software.
- Describe the creation of simple proton irradiation plans, evaluate them from a clinical perspective, and apply what they have learned to a specific project.

**5 Examination**

Course achievement: written project report
Module exam: will be announced at the beginning of the course.

**6 Participation requirements**

No

**7 Module type**

Elective module

| 8 | **Responsible**<br>Jun.-Prof. A. Lühr | **Faculty in charge**<br>Department of Physics |
|---|---|---|

| **Module:** TPS – Internship for radiation planning | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency**<br>WS+SS | **Duration**<br>1 semester | **Semester**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Practice | P | 6 | 2 |
| **2** | **Language:** German / English | | | | |
| **3** | **Content**<br>Introduction to the basics of radiation planning, carrying out contouring and radiation planning on simple phantoms, but also interactive or inverse creation of individual radiation plans for patients based on anonymized patient data. | | | | |
| **4** | **Learning outcome**<br>The students are familiar with the modules of a radiation planning system and various dose calculation methods. You know the volume concept in radiation therapy, the use of the most important imaging procedures with multimodal image registration and fusion, as well as the essential principles of plan optimization (protection of organs at risk, homogeneous irradiation of the target volume). You can operate a modern 3D/4D treatment planning system, evaluate isodose curves and interpret dose-volume histograms. | | | | |
| **5** | **Examination**<br>Coursework: Attendance; Preparation of protocols for the internship experiments; final oral group examination (30 min) | | | | |
| **6** | **Participation Requirements**<br>Basic knowledge of radiation physics and the interaction of radiation and matter is required. These can be acquired, for example, through successful participation in the module “Strahlungsphysik I”, “Medizinphysik I & II” and “Medizinphysikalisches Klinikpraktikum” of the Medical Physics bachelor’s degree program at the TU Dortmund. | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics | | | |
| **9** | **Teachers**<br>Christian Mehrens and Prof. Dr. Andreas Block (Klinikum Dortmund), Dr. Anne Bialek (TUDo) | | | | |

| **Module:** Basic radiation protection regulation for medical physics experts | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>1 | **Work load**<br>30 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture and practice | S | 1 | Block course |
| **2** | **Language:** German | | | | |
| **3** | **Content**<br>Basics: radiation physics, radioactivity, radiation biology, dosimetry, radiation planning. Dose estimates, personal dosimetry.<br>Radiation use on humans: justifiable indication<br>Natural and civilizational radiation exposure.<br>Radiation protection: basics, structural and equipment radiation protection, applications (e.g. in nuclear medicine). Legal basis. | | | | |
| **4** | **Learning outcome**<br>The students have acquired the knowledge that is imparted in a basic radiation protection course in accordance with legal regulations. | | | | |
| **5** | **Examination**<br>will be announced at the beginning of the event | | | | |
| **6** | **Participation requirements**<br>Basic mathematical and physical knowledge from the bachelor's degree program | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |
| **9** | **Teachers**<br>Prof. Dr. Andreas Block (Klinikum Dortmund), Jun.-Prof. Dr. Armin Lühr (TUDo) | | | | |

| **Module:** Fundamentals of Detector Physics | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:** annually in SS | **Duration:** 1 semester | **Semester:** 1. – 3. sem. | **Credits** 3 | **Work load** 90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Interactions of charged, neutral particles and of photons with matter, overview of overall detector systems, gas-filled ionization detectors (types and modes of operation, ionization and charge loss, motion in elctr. and magn. field, proportional chambers, drift chambers)<br>Field, proportional chambers, drift chambers, semiconductor detectors (basics, pn-junction and interfaces, types, pixel detectors), scintillation detectors (function, applications), calorimetry (electromagnetic and hadronic, homogeneous and sampling), particle identification, trigger systems, data acquisition systems (DAQ) | | | | |
| 4 | **Learning outcome**<br>Students gain an overview of the various detector designs used in particle physics, medical physics, and other fields. In particular, they learn the relationship between the respective primary interactions of the particles to be detected with the total matter traversed and the fractions exploited by the respective detector design. This leads to an understanding of the respective advantages and disadvantages of the construction types for different application purposes. Furthermore, the students are enabled to work with original literature. | | | | |
| 5 | **Examination**<br>Course credits: none.<br>Module Exam: Graded written or oral examination. | | | | |
| 6 | **Participation Requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Kevin Kröninger | **Faculty in charge**<br>Department of Physics | | | |

| **Module:** Applied Dosimetry | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>The course covers the basics of dosimetry and its applications. The course focuses on the aspect of personal dosimetry and its importance in radiation protection of exposed professionals. The seminar will cover the basics of detector physics as well as technological aspects of the application, such as dosimeter requirements and implementation in standardization. | | | | |
| 4 | **Learning outcome**<br>Students deepen their knowledge in the field of dosimetry through self-study for their own individual presentations. This lecture also trains skills in scientific research and presentation techniques. Scientific discussion techniques are acquired in the subsequent discussion. | | | | |
| 5 | **Examination**<br>Course Credits: Active participation in the discussions following the lectures.<br>Module examination: Graded own technical lecture | | | | |
| 6 | **Participation requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Kevin Kröninger | | | **Faculty in charge**<br>Department of Physics | |

| **Module:** Advanced MRI | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture (1h) | L | 6 | 4 |
| | 2 | Exercise Session (1h) | E | | |
| | 3 | Seminar (1h) | S | | |
| | 4 | Clinical Training (1h) | T | | |
| 2 | **Language:** English | | | | |

**3**

**Content**

Magnetic resonance imaging (MRI) is a non-ionizing imaging technique. MRI enables multidimensional (2D, 3D, 4D,...) and multicontrast ($T_1$-, $T_2$, $T_2$*, diffusion, perfusion, susceptibility,...) in-vivo (human or animals) or ex-vivo (forensic, various substances, cell culture) imaging using either exogenous contrast agents or endogenous substances (blood, tissue components).

The well-functioning combination of different hardware and software components based on physical and mathematical principles allows the creation of an MRI image that can be used for both scientific and diagnostic purposes. The MRI images can be evaluated either qualitatively or quantitatively. A quantitative evaluation enables both an objective assessment of the MRI images independent of the user's professional experience and the use of appropriate MRI methods in the context of long-term examinations and drug treatments.

The focus of this four-part course is on 1) understanding the formation of different image contrasts from a physical point of view, 2) analyzing quantitative MRI images using different programming languages, 3) preparing a scientific presentation on an MRI-related topic based on current literature, and 4) practical experience with the MRI techniques and contrasts presented in the course.

**Literature:**

- Mona Salehi Ravesh; Lecture notes, TU Dortmund University, 2024.
- Bernstein M. et al; "Handbook of MRI pulse sequences", Academic Press
- Haacke M. et. Al.; "Magnetic Resonance Imaging: Physical Principle and Sequence Design", Wiley
- Schlegel W. et. Al.; "Medical Physics", Springer
- www.pubmed.org
- https://mriquestions.com/index.html

**4**

The lecture covers the basics of magnetic resonance imaging and MRI weighting ($T_1$, $T_2$, $T_2$*, perfusion, diffusion weighting), which are necessary for understanding quantitative MRI techniques.

As part of exercises, students will implement mathematical-physical methods in a programming language of their choice, which will be used for the quantitative analysis of the MRI methods covered in the lecture.

In a seminar, students will be able to extract the essence of selected research articles and present recent advances in the application of quantitative MRI techniques to human imaging. This gives students practical experience and develops their presentation skills, which are essential for future research activities and international conferences.
As part of a subsequent practical course, students will be able to perform in vitro (phantom) examinations on a human MRI machine, giving them hands-on experience of the techniques covered and the image contrasts within this course. In addition, they will gain their first experience in producing a phantom that can be used for a specific question (quantitative relaxometry). This will provide students with practical experience and develop their decision-making skills, which are essential for future research activities.

**5**

**Examination**

Course credit: Active participation in the exercises, 20-minute seminar presentation, 2-3-page practical report.
Module exam: oral exam (30 min)

| | | |
|---|---|---|
| **6** | **Participation Requirements**<br>Knowledge from the courses "Theoretical Physics II" and "Experimental Physics III" is desirable, but not mandatory for understanding the topics in this course. | |
| **7** | **Module type**<br>Elective module/ mandatory module | |
| **8** | **Responsible**<br>PD Dr. habil rer. nat. Mona Salehi Ravesh | **Faculty in charge**<br>Department of Physics |

| **Module:** Image processing in medicine | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture+ Tutorial | L+T | 5 | |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Reception by the human visual system, definition and basics of image processing (e.g. discretization, sampling theorem, global parameters of images), operations in the spatial domain (histogram modulation, filtering, morphological operations, geometric<br>Image operations, distance transformation), information extraction methods (segmentation, texture analysis, shape description), classification and machine learning (support vector machines, deep learning), image restoration, image registration, visualization. | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>- Can students confidently apply the basics of two- and multi-dimensional signal processing.<br>- The students master techniques and strategies in order to be able to solve typical tasks in image processing independently.<br>- The students have in-depth programming knowledge in MATLAB through exercises.<br>- The students are qualified to analyze cross-disciplinary, interdisciplinary questions through the application area of medical image processing.<br>- The students are prepared to work on further questions in medical image processing in the research phase. | | | | |
| **5** | **Examination**<br>will be announced at the beginning of the event | | | | |
| **6** | **Participation requirements**<br>Confident handling of Fourier transformation and description of systems in the frequency domain (time frequencies / spatial frequencies) | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Prof. Dr.-Ing. Georg Schmitz | | | **Faculty in charge**<br>RUB | |

| **Module:** Ultrasound in medicine | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture+ Tutorial | L+T | 5 | |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Linearized acoustic field equations in fluid media and elastic solids, scattering and attenuation in biological tissues, the piezoelectric effect, ultrasonic transducers (structure, equivalent circuits), imaging methods with ultrasonic transducer arrays, flow measurement and Doppler methods, ultrasound contrast agents, selected special areas (elastography, photoacoustics, harmonic imaging, HIFU therapy, superresolution imaging) | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>- Students know the basic linear acoustic equations and can explain the linearizations used and derive the linear wave equation in inhomogeneous media.<br>- The students know the basic quantities and relationships for the propagation of ultrasound waves in solid bodies.<br>- Students can model the acoustic properties of biological tissue (scattering, attenuation).<br>- The students know how conventional clinical ultrasound devices work, can describe the structure of ultrasound transducers and are able to implement simple reconstruction procedures (delay-and-sum).<br>- The students are prepared to work on further questions regarding imaging and therapeutic ultrasound systems in the research phase. | | | | |
| 5 | **Examination**<br>will be announced at the beginning of the event | | | | |
| 6 | **Participation requirements**<br>Confident handling of Fourier transformation and description of systems in the frequency domain (time frequencies / spatial frequencies) | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr.-Ing. Georg Schmitz | | | **Faculty in charge**<br>RUB | |

| **Module:** Applications of Machine Learning in Medical Physics | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Machine learning has been increasingly used in many areas of medicine for years and even has the potential to change them completely. Already today, machine learning methods are of great importance, for example, in diagnostics with the help of imaging procedures. There, machine learning methods help physicians to evaluate the highly complex data in order to make a diagnosis more precisely and faster. But machine learning can also be used efficiently in other areas, such as therapy planning, treatment or even in the development of effective drugs, not only to save costs and time, but ultimately to provide patients with the best possible care.<br>In this seminar, you will first get an overview of the diverse applications of machine learning in medicine. In addition, you will scientifically research a selected topic, gain a deeper insight and understanding, and clearly prepare and present it as a lecture. The central focus of these seminar lectures is on the medical-physical applications, less on the technical aspects of machine learning.<br>In addition to the seminar lectures, we prepare short lecture inserts in which we take a closer look at the technical aspects of machine learning in the respective applications and explain them without any necessary prior knowledge. | | | | |
| **4** | **Learning outcome**<br>The participants get an overview of current topics in medicine, in which modern machine learning methods are used. You will learn how to research a scientific topic and present it to an audience in a comprehensible lecture. In addition, you will gain insights into how modern machine learning algorithms work. | | | | |
| **5** | **Examination**<br>Course Credits: Active participation in the discussions during the seminar hours.<br>Module examination: Graded, independently researched and elaborated seminar presentation. | | | | |
| **6** | **Participation requirements**<br>Basic knowledge in medical physics, desirable is the lecture 'Statistical Methods of Data Analysis'. | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Prof. Dr. Kevin Kröninger | **Faculty in charge**<br>Department of Physics | | | |

# Track B: Physics of Living Systems

| Mandatory courses | Sem. | CP |
|---|---|---|
| Physics of life | WS | 6 CP |
| Lab course: Physics of Living Systems | SS | 5 CP |
| AI for Medical Applications | WS | 9 CP |
| | | |
| **Elective courses** | | |
| Soft Matter | SS | 6 CP |
| MD Simulation of Biological Materials | WS | 6 CP |
| Neuroinformatics | WS/SS | 6 CP |
| Biomaterials | WS | 4 CP |
| Tissue Engineering | SS | 4 CP |
| Medicinal Chemistry 1 | WS | 4 CP |
| Medicinal Chemistry 2 | SS | 4 CP |
| Fundamental Immunology | SS | 4 CP |
| Biomolecular Modelling | WS | 4 CP |

Note: Electives can also be suggested proactively. An informal proposal including the description of the course should be send to the secretary of the chair of the program.

# Mandatory courses

| **Module:** Physics of life (**BP12**) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Tutorial | L+T | 6 | 4 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>i) Thermodynamics, phase transformations and critical phenomena in biology. Role of fluctuations, Landau-Ginzburg, connection to all other areas<br>ii) Mechanics of the cell: elasticity of shells, Helfrich theory, wetting, cell adhesion according to Sackmann, budding line tension.<br>iii) Electrostatics on biopolymers and membranes: Poisson-Boltzmann, Gouy Chapmann, coupling to phase transformations<br>iv) Polymer Theory: Gauss and Flory Chain, Dynamics (Rousse and Zimm), De Gennes, Reptation, Semiflexible Polymer<br>v) Viscoelasticity theory of biopolymer networks/cytoskeleton. Affine networks, scale arguments, rubber plateau, dynamics and elasticity<br>vi) Life at small Reynolds numbers. Microswimmer, reversibility, slender body theory (sperm, bacteria, paramecium, lungs,...)<br>vii) Non-linear phenomena. (coupled) nonlinear oscillators (hearing), solitons, application nerves, heart...<br>viii) Evolution theory | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>– Students can apply physical concepts of hydrodynamics, elasticity theory, thermodynamics/statistics and electrodynamics in an interdisciplinary manner to questions of biological and medical physics (especially) on a mesoscopic and macroscopic scale.<br>– In the exercises, students learned to independently understand problems from the interdisciplinary subject area of biological physics and physiology as physical problems, to solve them and to discuss them in the group. | | | | |
| **5** | **Examination**<br>Graded exam (120 min) or oral exam (30 min), will be announced at the beginning of the course | | | | |
| **6** | **Participation Requirements**<br>No | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. Matthias Schneider | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Lab course to Physics of Living Systems | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:** SS | **Duration:** 1 semester | **Semester:** 1. – 3. sem. | **Credits** 6 CP | **Work load** 180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lab | P | | |
| 2 | **Language: English** | | | | |
| 3 | **Content**<br>Experimental introduction to central working methods from biophysical research i.e.<br>• Electrophysiology<br>• Lipids and Membrane Biophysics<br>• Fluorescence microscopy<br>• FRET<br>• Contraction Force microscopy<br><br>The respective experiment instructions only contain a brief outline of the theoretical and experimental basics. The necessary knowledge must be acquired through self-study. | | | | |
| 4 | **Learning outcome**<br>The students earn the practical knowledge that is necessary for successful independent experimental work in the field of biophysical research. The students are familiar with different techniques and their respective theoretical background. | | | | |
| 5 | **Examination**<br>Oral Exam (30min) | | | | |
| 6 | **Participation Requirements**<br>Physics of Life | | | | |
| 7 | **Module type**<br>Elective module/ mandatory module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Matthias Schneider | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** AI for Medical Applications | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>2. – 3. sem. | **Credits**<br>9 | **Work load**<br>270 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture (2h) + Tutorial (4h) | L+T | 9 | 6 |
| 2 | **Language: English** | | | | |
| 3 | **Content**<br>• Motivation – What are the goals and what tools are required to attain them?<br>• Medical Data – Types, Standards & Multimodality<br>• Machine Learning Basics I & II<br>• Basic and advances Computer Vision with Deep Learning. What does the computer see?<br>• Natural Language Processing – From Basics to Large Language models. How does the computer read?<br>• Introduction to Generative AI – GAN and Diffusion models<br>• Timeseries Analysis with classical methods and AI<br>• Introduction to AI Agents<br>• What else is there? Pointers to other methods and bleeding edge developments.<br><br>Exercises accompanying the lecture content. The algorithms and approaches are implemented and evaluated using real medical data sets. Students will have access to a learning platform with GPUs to train their models. | | | | |
| 4 | **Learning outcome**<br>• Participants will be able to assess the importance of AI in medicine<br>• Know about types of medical data and how to handle it<br>• Understand how to apply classic machine learning and AI algorithms to medical images and clinical text<br>• After the course, participants will be able to familiarize themselves independently with more advanced AI procedures and apply (i.e. programming) them to the medical domain | | | | |
| 5 | **Examination**<br>Graded exam (90 min) or oral exam (30 min), will be announced at the beginning of the course | | | | |
| 6 | **Participation Requirements**<br>• Solid programming skills in Python or similar language<br>• Experience with git, ssh and command line tools desirable | | | | |
| 7 | **Module type**<br>Mandatory module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Dr. Jens Kleesiek,<br>Prof. Dr. Michael Kamp | | **Faculty in charge**<br>Medical Faculty UDE / Department of Physics | | |

# Elective courses

| **Elective courses** | |
|---|---|
| Soft Matter | 6 CP |
| MD Simulation of Biological Materials | 6 CP |
| Neuroinformatics | 6 CP |
| Biomaterials | 4 CP |
| Tissue Engineering | 4 CP |
| Current Topics in Cell Biology | 4 CP |
| Biomolecular Modelling | 4 CP |
| Mediclinal Chemistry 1 | 4 CP |
| Mediclinal Chemistry 2 | 4 CP |
| Fundamental Immunology | 4 CP |

| Module: Theory of Soft and Biological Matter (PHY633) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:** SS | **Duration:** 1 semester | **Semester:** 2. sem. | **Credits** 6 | **Work load** 180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with Exercise | L+T | 6 | 3 + 1 |
| 2 | **Language: English** | | | | |
| 3 | **Content**<br>Important soft and biological matter systems: colloidal systems, liquid crystals, polymers, fluid interfaces, fluid membranes; cell membrane, DNA, cytoskeleton, proteins, motor proteins, protein filaments.<br>1. Statistical physics:<br>virial expansion, phase transitions (MeanField, scale laws).<br>2. Molecular interactions:<br>Debye-Hückel theory, van der Waals interaction, DLVO theory, hydrophobic effect, hydrogen bonds, steric interactions.<br>3. Polymers:<br>chain models, self-avoidance, polymer solutions, adsorption, rubber elasticity.<br>4. Fluid interfaces:<br>surface tension, differential geometry, surfaces of constant curvature, capillary waves, wetting, foams.<br>5. Membranes:<br>bending energy, liquid vesicle shapes, thermal fluctuations.<br>6. Stochastic dynamics:<br>Brownian motion, diffusion problems, random walk, Markov processes, Langevin equation and Fokker-Planck equation.<br>7. Physical and chemical kinetics:<br>thermally activated processes, chemical equilibrium, chemical kinetics, Michaelis-Menten.<br>8. Biological physics:<br>molecular motors, filaments, ATP-driven processes. | | | | |
| 4 | **Learning outcome**<br>Students will be able to apply modern methods of theoretical physics (from the fields of statistical physics, mechanics, electrodynamics) to systems of soft matter and biological physics in an interdisciplinary way. In the exercises, the students learn to understand problems from the interdisciplinary subject area of Soft Matter as theoretical-physical problems, to solve them and to discuss them in groups. | | | | |
| 5 | **Examination**<br>course work: Exercises Module examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course. | | | | |
| 6 | **Participation Requirements** | | | | |
| 7 | **Module type** | | | | |
| 8 | **Responsible**<br>Prof. Dr. Jan Kierfeld | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Molecular Simulation of Soft Matter and Biological Materials **(PHY714)** | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M. Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with practical course (exercise) | L+T | 6 | 3+1 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>1. Applications in relevant molecular systems:<br>Biological soft matter: proteins and lipid membranes.<br>Industrial materials: polymers, metals, surfactants and graphene.<br>2. Simulations of molecular systems:<br>Molecular dynamics: underlying approximations, efficient algorithms, integration of Newton's equations of motion, time reversibility, ensembles (barostats and thermostats).<br>Monte Carlo simulations and heuristic sampling methods (e.g., Evolutionary algorithms)<br>Coarse-graining and mesoscopic simulation methods.<br>3. Free energy calculations: Reaction coordinates, free energy perturbation, thermodynamic integration, umbrella sampling, strings methods.<br>4. Non-equilibrium thermodynamics:<br>Jarzynski Equation and Crooks Theorem | | | | |
| **4** | **Learning outcome**<br>Students learn to apply modern compter methods (from the fields of statistical physics, mechanics) to molecular systems of soft matter and biological physics in an interdisciplinary manner. The power and relevance of these methods are demonstrated using exciting examples from the scientific literature. In the exercises, students learn to translate problems from the interdisciplinary subject area of soft matter into a computational-physical problem, to address them and to discuss them in the group. | | | | |
| **5** | **Coursework and examination requirements**<br>Course work: Practical exercises<br>Module exam: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course. | | | | |
| **6** | **Participation Requirements**<br>None | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. H. J. Risselada | | **Faculty in charge**<br>Department of Physics | | |

# Neuroinformatics.

This subject area offers a variety of courses.

| | |
|---|---|
| **Machine Learning** | * |
| Introduction to Data Science | WS |
| Deep Learning | WS |
| Natural Language Processing with Deep Leaning | WS |
| Supervised Methods | SoS |
| Unsupervised Methods | WS |
| | |
| **Machine Learning** | |
| Introduction to Computational Neuroscience | SoS |
| Single-Neuron Models | SoS |
| Neural Dynamics | WS |

* the selection of courses offered varies to some degree each year.

Detailed descriptions of the courses can be found below (see Subject area Neuroinformatics ).

| **Module:** Biomaterials: From Cells to Tissues | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual, WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Biomaterials: From cells to tissues | L | 3 | 2 |
| | 2 | Exercise for Biomaterials: From cells to | T | 1 | 1 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>1) Introduction to biological tissues<br>− properties at the cellular scale<br>− properties at the macromolecular scale: composition of the extracellular matrix<br>2) Interactions between cells and their native tissue environment<br>− soluble signals<br>− matrix-bound cues<br>− matrix mechanics<br>− cell-cell interactions<br>3) Biomaterials and scaffolds: definitions and fundamental properties<br>− biocompatibility, biodegradability, structural and functional support for cells<br>4) Types of biomaterial scaffolds<br>− natural biomaterials (decellularized tissues, ECM protein hydrogels)<br>− synthetic polymeric biomaterials<br>5) Scaffold design and biomaterial properties<br>− structure (porosity, fibrous)<br>− mechanical and degradative properties<br>− biochemical composition<br>− topography<br>6) Scaffold fabrication techniques<br>− hydrogel synthesis and functionalization<br>− techniques to introduce porosity<br>− fiber electrospinning<br>− 3D printing<br>7) Biomaterials in 2D versus 3D cell culture: applications<br>8) Regulation of cell function by biomaterial properties<br>− cell-matrix interactions (e.g. cell adhesion, mechanotransduction)<br>− cell migration<br>− stem cell proliferation and differentiation | | | | |
| **4** | **Learning outcome**<br>After module completion, students will be able to<br>– explain basic design principles in modern biomaterials and cell culture scaffolds<br>– understand how properties of biomaterials regulate cell function and apply this knowledge to custom-design biomaterials for specific cell culture applications<br>– develop design strategies for biomedical applications at the interface of chemistry, materials science and cell biology<br>– independently familiarize themselves with a biomedical topic/problem in a scientific manner<br>– present complex interdisciplinary biomedical topics in spoken and written language using the correct scientific terminology | | | | |
| **5** | **Examination**<br>Coursework: seminar presentation,<br>module examination: oral or written examination. | | | | |
| **6** | **Participation Requirements**<br>None,<br>Basic knowledge of cell biology, comparable to courses on cell biology in the Bachelor's program in chemical biology and basic knowledge on biochemistry are recommended. | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. B. Trappmann | | **Faculty in charge**<br>Department of Chemistry and Chemical Biology | | |

| **Module:** Tissue Engineering | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual, SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Tissue Engineering | L | 3 | 2 |
| | 2 | Exercise for Tissue Engineering | T | 1 | 1 |
| **2** | **Language: English** | | | | |

**3 Content**

1. Basic principles of tissue engineering
2. Biomaterials in tissue engineering
− Scaffolds: design, materials, fabrication and characterization
3. Cell source: isolation, expansion, differentiation
4. In vitro control of tissue development
− Microfluidic platforms
− Principles of bioreactor design
5. Gene therapy
6. Current applications
− Skin
− Heart
− Bone
− Muscle
− Nervous system
7. Fundamentals of drug delivery
8. In vivo transplantation of engineered tissues
9. Clinical translation
10. Applications of engineered tissues in drug testing/ replacement of animal models
11. Current challenges of tissue engineering and outlook on future possibilities

**4 Learning outcome**

After module completion, students will be able to

- explain basic design principles in tissue engineering and regenerative medicine
- understand the criteria for choosing an appropriate combination of cell source, scaffolds and bioreactors to engineer specific tissues
- apply tissue engineering principles to address clinical problems
- demonstrate knowledge of already existing clinical applications of tissue engineering and their limitations
- independently familiarize themselves with a biomedical topic/problem in a scientific manner
- present complex interdisciplinary biomedical topics in spoken and written language using the correct scientific terminology

**5 Examination**

Coursework: seminar presentation,
module examination: oral or written examination.

**6 Participation Requirements**

None,
Basic knowledge of cell biology, comparable to courses on cell biology in the Bachelor's program in chemical biology and basic knowledge on biochemistry are recommended.

**7 Module type**

Elective module/ mandatory module

| | | |
|---|---|---|
| **8** | **Responsible**<br>Prof. Dr. B. Trappmann | **Faculty in charge**<br>Department of Chemistry and Chemical Biology |

| **Module:** Current Topics in Cell Biology | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual, WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Current Topics in Cell Biology | L | 3 | 2 |
| | 2 | Seminar for Current Topics in Cell Biol- | S | 1 | 1 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>Insights into current topics and methods in cell biology from the following fields:<br>1. From DNA to protein – the flow of the genetic information<br>2. Cellular Signalling – from signals to responses<br>3. Genome Maintenance and architecture of the nucleus | | | | |
| **4** | **Learning outcome**<br>After module completion, students will be able to<br>– acquire the ability to effectively read and work with the current scientific literature in the field of cell biology<br>– develop strategies for presenting the research work of others – from hypothesis to conclusion<br>– confidently present cell biological topics in spoken and written language using the correct scientific terminology<br>– put the content of articles from selected research papers and research work of others into context<br>– independently familiarize themselves with a current topic in cell biology<br>– understand in detail specific functions in the cell including the flow of the genetic information, cell signalling and how DNA - the carrier of the genetic information is maintained<br>– explain the theoretical background of modern cell biological methods - from application to analysis of develop design strategies for biomedical applications at the interface of chemistry, materials science and cell biology<br>– formulate relevant questions for cell biological research | | | | |
| **5** | **Examination**<br>Module examination: presentation of a research paper in the seminar with discussion.<br>Attendance of seminars is compulsory, as teaching and learning content will be acquired through presentations of the current literature and discussions. Therefore, the learning objectives can only be achieved through regular participation. Presence on all but max. 3 seminars is required for successful participation. | | | | |
| **6** | **Participation Requirements**<br>None,<br>Basic knowledge of cell biology, comparable to courses on cell biology in the Bachelor's degree program in chemical biology and basic knowledge on biochemistry are recommended. | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. B. Pfander | | **Faculty in charge**<br>Department of Chemistry and Chemical Biology | | |

| **Module:** Biomolecular Modeling | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Biomolecular Modeling | L | 3 | 2 |
| | 2 | Exercises for Biomolecular Modeling | T | 1 | 1 |
| 2 | **Language: English** | | | | |
| 3 | **Content**<br>1. Basics<br>− Molecular coordinate systems<br>− Classical mechanics<br>− Statistical mechanics<br>− Principles of Monte Carlo simulation<br>− Principles of molecular dynamics simulations<br>− Optimization methods/vibration analysis<br>2. Atomic models for biological systems<br>− Intra- and intermolecular potential functions<br>− Potential parametrization<br>− Construction principles of complex molecular models<br>− Efficient calculation methods<br>3. Calculation of observables<br>− Thermodynamic quantities<br>− Structural variables, distribution functions<br>− Dynamic quantities, time correlation functions<br>− Comparison with experimental data<br>4. Special simulation techniques<br>− Creation of different ensembles<br>− Free energy simulations<br>− The Potential of Mean Force<br>− Advanced methods<br>5. Applications<br>− Biological membranes<br>− Protein dynamics<br>− Protein-ligand binding | | | | |
| 4 | **Learning outcome**<br>Upon successful completion of the module, students will be able to,<br>– explain different simulation and modeling methods for biological systems,<br>– propose suitable calculation methods for given applications and questions and to estimate the limits of their predictive power and the effort required,<br>– select and apply appropriate programming techniques for problem solving,<br>– use acquired knowledge to develop methodical solution strategies for biochemical and biophysical problems and to logically analyze the results,<br>– develop solution strategies, discuss, present their own point of view appropriately orally and in writing as well as cooperate with others. | | | | |
| 5 | **Examination**<br>Oral examination | | | | |
| 6 | **Participation Requirements**<br>None | | | | |
| 7 | **Module type**<br>Elective module/ mandatory module | | | | |
| 8 | **Responsible**<br>Prof. Dr. S. M. Kast | | **Faculty in charge**<br>Department of Chemistry and Chemical Biology | | |

| **Module:** Medicinal Chemistry 1 | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual, WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Medicinal Chemistry 1 | L | 3 | 2 |
| | 2 | Exercise for Medicinal Chemistry 1 | T | 1 | 1 |
| 2 | **Language: English** | | | | |

**3 Content**

1. Fundamentals of protein-ligand interaction:
- Methods for understanding protein-ligand interactions as a basis for the rational design of W agents.
2. Basic concepts of medicinal/pharmaceutical chemistry:
- Definition of active substance
- Drug substance and medicinal product, how do active substances work?
- Phase I-IV clinical trials
3. Basic concepts of the description of pharmacokinetics:
- LADME concept and terms
- Application routes
4. Independent pharmacokinetic characteristics:
- Understanding of clearance parameters,
- Volume of distribution
- Bioavailability
- Half-life
- Elimination
5. Structural properties and possibilities for optimising pharmacokinetic properties:
- Lipinsky Rules and Innovations
- Metabolic processes
- Prediction of ADME properties on the basis of calculated parameters
6. Prediction of human PK properties:
- Transporter properties
- Microsomal stability
- Caco 2 assay
- Scaling methods
7. Structure-based drug design and computer methods of modern drug discovery:
- Visualisation of physicochemical properties of active substances
- molecular modelling
- virtual screening
- Database searches
8. Case studies:
- Factor Xa inhibitors
- MMP inhibitors
- Kinase inhibitors
- Lipid 2 antagonists
- PDE5 inhibitors
- Adenosine agonists
- sGC stimulators
- sGC activators
- DPP4 inhibitors

**4 Learning outcome**

By successfully completing this module, students will be able to,

– explain basic principles of protein-ligand interaction and modern drug discovery.
– comprehend structure-based, rational and computer-based methods for the development of active substances
– explain factors that influence the interplay of pharmacokinetics and pharmacodynamics and understand the possibilities for influencing these processes through chemical modification and apply them in problem solving.
– develop interdisciplinary solution strategies for practical problems at the interface between chemistry, pharmacology and biophysics for basic research and biomedical applications.
– discuss, communicate their own point of view appropriately and cooperate with others when developing solution strategies.

| | | |
|---|---|---|
| 5 | **Examination**<br>Written exam | |
| 6 | **Participation Requirements**<br>None,<br>knowledge of bioorganic chemistry and organic chemistry is recommended | |
| 7 | **Module type**<br>Elective module/ mandatory module | |
| 8 | **Responsible**<br>Prof. Dr. D. Rauh | **Faculty in charge**<br>Department of Chemistry and Chemical Biology |

| **Module:** Medicinal Chemistry 2 | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual, SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Medicinal Chemistry 2 | L | 3 | 2 |
| | 2 | Exercise for Medicinal Chemistry 2 | T | 1 | 1 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>1. History of drug research and discovery:<br>- Active plant ingredients<br>- Aspirin<br>- Process of synthesis of the active substance<br>2. Targets for pharmacologically active agents:<br>- Distribution of target classes for commercial agents<br>3. Protein-ligand interactions:<br>- Significance of the individual energy contributions<br>- Strength of different types of interaction<br>4. Enzyme inhibitors:<br>- Types of enzyme inhibition and their kinetic description<br>- Types of enzyme inhibition and their kinetic description<br>- Mechanisms of different protease types<br>- Proteasome and proteasome inhibitors<br>5. Industrial pharmaceutical research:<br>- Screening process<br>- Screening by selection<br>- Computational chemistry methods in the hit finding and hit-to-lead process<br>- Optimisation cycles<br>6. Case studies:<br>- Factor Xa inhibitors<br>- MMP inhibitors<br>- Kinase inhibitors<br>- Lipid 2 antagonists<br>- PDE5 inhibitors<br>- sGC stimulators<br>- sGC activators<br>- DPP4 inhibitors<br>7. Biological drugs such as oligonucleotides and antibodies | | | | |
| **4** | **Learning outcome**<br>By successfully completing this module, students will be able to,<br>– explain the processes of pharmaceutical research and industrial applications.<br>– understand the underlying principles for the action of biological drugs<br>– understand different technologies for drug identification<br>– describe different types of enzyme inhibition and to draw conclusions about possible consequences of enzyme inhibition from chemical structural features.<br>– develop interdisciplinary solution strategies for practical problems at the interface between chemistry, pharmacology and biophysics for basic research and biomedical applications.<br>– discuss, communicate their own point of view appropriately and cooperate with others when developing solution strategies. | | | | |
| **5** | **Examination**<br>Written exam | | | | |
| **6** | **Participation Requirements**<br>None,<br>knowledge of bioorganic chemistry and organic chemistry is recommended | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. D. Rauh | | **Faculty in charge**<br>Department of Chemistry and Chemical Biology | | |

| **Module:** Fundamental Immunology | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>annual, SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>4 | **Work load** |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Fundamental Immunology | L | 3 | 2 |
| | 2 | Exercises for Fundamental Immunology | T | 1 | 1 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>1. organs and cell types of the immune system<br>2. immunological processes during viral or bacterial infections<br>3. immunological effector mechanisms of infection control<br>4. basics of immunological anti-tumor response<br>5. novel immunologic therapeutic approaches<br>- therapy with monoclonal antibodies,<br>- cell therapy,<br>- immunosuppressive drugs,<br>- bone marrow transplantation<br>6. basics of signal transduction in immune cells<br>- Signal transduction of cytokines,<br>- T cell receptor,<br>- inhibitory receptors | | | | |
| **4** | **Learning outcome**<br>By successfully completing this module, students will be able to,<br>– understand the different cell types and organs of the immune system and their functions based on their knowledge acquired in the course.<br>– understand the interaction of the different components of the immune system in a successful immune response.<br>– understand and evaluate experimental approaches for the investigation of immunological processes.<br>– explain various manipulations of the immune system for therapeutic purposes.<br>– present scientific facts in technically correct terms in speech and in writing and to discuss them with others. | | | | |
| **5** | **Examination**<br>Written exam | | | | |
| **6** | **Participation Requirements**<br>None,<br>basic knowledge of cell biology comparable to courses on cell biology in the bachelor's degree program in chemical biology is recommended. | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. Carsten Watzl | | **Faculty in charge**<br>Department of Chemistry and Chemical Biology | | |

# Free Electives

Every course that is part of specialization Track A and B can also be chosen as a free elective. For these courses, the module descriptions can be found under the descriptions of Track A and Track B.
Courses provided by the Department of Physics of the TU Dortmund University are also eligible as Free Electives.

## Subject area Clinical Medical Physics

| Module | CP |
|---|---|
| Advanced Clinical Medical Physics | 6 |
| Radiation applications in the clinic | 3 |
| Modern Radiotherapy | 6 |
| Medical Physics and Technology in Particle Therapy | 3 |
| Applied Proton Therapy | 6 |
| TPS – Practical Course on Treatment Planning | 6 |
| Basic radiation protection regulation for medical physics experts | 1 |
| Fundamentals of Detector Physics | 3 |
| Applied Dosimetry | 3 |
| | |
| Detector systems in particle and medical physics | 3 |

| **Module:** Detector systems in particle and medical physics | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency**<br>in WS | **Duration**<br>1 semester | **Semester**<br>1. – 3. sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Different types of detectors used in particle and/or medical physics, e.g. semiconductor and scintillation detectors, X-ray detection systems. Detector systems and components composed of different types, e.g. calorimeters, modern particle physics experiments, PET, CT, etc. | | | | |
| 4 | **Learning outcome**<br>The seminar will deepen the knowledge of the different types of detectors which are used in particle physics and in medical physics. The important lectures on systems and trigger systems allow to understand the interplay of the different detector designs to be understood. The prescribed own lecture leads to a very intensive study of a special topic and also trains competences in the field of scientific literature research and presentation techniques. | | | | |
| 5 | **Examination**<br>Coursework: Active participation in the discussion.<br>Graded module examination: oral presentation on one of the topics of the seminar | | | | |
| 6 | **Participation Requirements**<br>Recommended: Fundamentals of Detector Physics | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | **Organization**<br>Department of Physics | | | |

# Subject area Medical Imaging

| Module | CP | Department |
|---|---|---|
| Advanced Medical Imaging | 6 | TU Phys |
| Advanced Magnetic Resonance Imaging | 6 | TU Phys |
| Image Processing in Medicine | 5 | RUB ET |
| Ultrasound in Medicine | 5 | RUB ET |
| | | |
| Tomographic imaging methods | 5 | RUB ET |
| Master's internship in medical technology | 3 | RUB ET |
| Master's seminar in medical technology | 3 | RUB ET |
| Biomedical Optics | 3 | RUB ET |
| Applied data visualization for medical physicists | 6/9 | TU Comp |
| Medical image processing | 6/9 | TU Comp |
| Seminar - Medical Image and Signal Processing | 6/9 | TU Comp |

| **Module:** Tomographic imaging methods | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture+ Tutorial | L+T | 5 | |
| **2** | **Language:** English? | | | | |
| **3** | **Content**<br>Generation and detection of X-rays, interactions of X-rays with matter, CT reconstruction methods (Fourier slice theorem, filtered back projection), practical aspects of image reconstruction, nuclear magnetic resonance effect, FID/spin echoes/gradient echoes, spatial coding in MRI, k-space description the MRI, simple basic sequences (spin echo, TSE, EPI, GRASE, BOLD), acoustic wave equation and Fourier diffraction theorem. | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>● Students know the basic tomographic reconstruction methods for X-ray computed tomography (CT), magnetic resonance imaging (MRI) and acoustic diffraction tomography.<br>● Can the students compare the tomographic imaging methods and explain their imaging properties (contrast mechanism, spatial and time resolution). In particular, they can describe the imaging properties in the spatial frequency space.<br>● The students know the basic technical structure of the systems for CT and MRI.<br>● Students can practically implement simple reconstruction algorithms.<br>● The students are prepared to work on further questions for imaging systems in the research phase. | | | | |
| **5** | **Examination**<br>will be announced at the beginning of the event | | | | |
| **6** | **Participation requirements**<br>Confident handling of Fourier transformation and description of systems in the frequency domain (time frequencies / spatial frequencies) | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Prof. Dr.-Ing. Georg Schmitz | | **Faculty in charge**<br>RUB | | |

| **Module:** Master's internship in medical technology | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Practice | P | 3 | |
| 2 | **Language:** English? | | | | |
| 3 | **Content**<br>The internship includes four experiments, each of which is carried out on several dates. In addition to recording measurement data, it is often necessary to evaluate algorithms that have to be programmed as part of the internship. The four experiments have the topics:<br>- Basics of ultrasound pulse-echo imaging<br>- Optimization of ultrasonic transducers with the Finite Element Method (FEM) with a professional commercial FEM program that is used, among others, by the most important manufacturers of medical ultrasound devices.<br>- Design and optimization of array systems for imaging, complete simulation of imaging ultrasound devices from data acquisition to image.<br>- Registration of medical image data using the example of computer-assisted surgery. | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>- Students can practically solve exemplary questions about imaging systems.<br>- The students have acquired in-depth knowledge of programming with Matlab.<br>- Using an example, the students learned how to technically optimize a system based on finite element methods.<br>- The students can present a test result in the form of a technical report correctly in terms of content and form.<br>- The students practiced sensibly dividing complex activities into small teams. | | | | |
| 5 | **Examination**<br>Test certificate after successful completion of the test and submission of the test report. Before the experiment is carried out, the knowledge required for the experiment is asked (10 minutes) and must be available in sufficient quantity. | | | | |
| 6 | **Participation requirements**<br>Confident handling of Fourier transformation and description of systems in the frequency domain (time frequencies / spatial frequencies) | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr.-Ing. Georg Schmitz | | **Faculty in charge**<br>RUB | | |

| **Module:** Master's seminar in medical technology | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | |

**2 Language:** English?

**3 Content**

The seminar basically covers topics from the area of imaging and image processing of medical image data. The main topic is chosen anew every semester and announced on the website of the Chair of Medical Technology at the beginning of the semester or in the preliminary discussion of the event.

**4 Learning outcome**

After successfully completing the module

- Students can independently review literature on a given topic and grasp and reproduce the essential content.
- The students master key skills for presenting their results, such as the written summary of the research results (literature study) and the presentation of the results.
- Students are enabled to express constructive criticism of the work of colleagues (peer review) and to formulate questions regarding content.

**5 Examination**

The coursework is achieved in the form of a lecture and participation in the discussion of other lectures.

**6 Participation requirements**

no

**7 Module type**

Elective module

| 8 | **Responsible** | **Faculty in charge** |
|---|---|---|
| | Prof. Dr.-Ing. Georg Schmitz | RUB |

| **Module:** Biomedical Optics | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Basics of the interaction of light and biological tissues, instrumentation for biomedical optical imaging, microscopy, optical coherence tomography (OCT), other tomographic optical methods, treatment of diseases with light (e.g. laser surgery). | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>- The students have learned to follow a lecture in English<br>- The students know the essential interaction mechanisms between light and biological tissue.<br>- Students understand various methods of optical imaging of biological tissue and the treatment of diseases with light. | | | | |
| 5 | **Examination**<br>The coursework is achieved in the form of a lecture and participation in the discussion of other lectures. | | | | |
| 6 | **Participation requirements**<br>no | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. rer. nat. Martin Hofmann | | **Faculty in charge**<br>RUB | | |

| **Module:** Applied data visualization for medical physicists | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 or 9 | **Work load**<br>180 h or 270h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | 2 | Exercise (optional) | T | 3 | 2 |
| **2** | **Language:** English? | | | | |
| **3** | **Content**<br>With the increasing size of data volumes in practically all areas as well as their complexity and changeability, visualization is becoming increasingly important. It serves both for intuitive representation and as a means of analysis. Corresponding visualizations are often achieved by mapping onto graphic scenes, which are then displayed efficiently using graphic data processing methods. The first part of the module covers basic concepts for visualizing and analyzing data of different types. Data types considered are in particular one- and two-dimensional functions, multi-dimensional functions, graphs and scattered point sets. Methods of graphical data processing, statistical data analysis, efficient discrete algorithms and data structures as well as applied mathematics are presented, on which the concepts and their realizations are based. Furthermore, existing visualization/analysis systems that provide corresponding concepts are discussed. The second part of the module presents advanced visualization concepts that are specifically relevant to medical physics. These concern volume data, as occurs in various imaging procedures, as well as vector and tensor fields. Furthermore, the use of visualization techniques in the analysis and prognosis of biomedical signals will be discussed, taking existing systems of computer-assisted diagnosis into account. | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>- Students have methodological knowledge that enables them to solve complex visualization and analysis tasks on data, e.g. B. result in connection with medical-physical requirements<br>- Students have applied methods that are available in existing systems and are based on original literature in their given form, but have also adapted them to new, possibly expanded questions and identified application limits and specific features | | | | |
| **5** | **Examination**<br>Coursework: none; Module examination or two partial achievements. If you only take the lecture: graded oral module examination. If the exercises are also completed: two partial achievements, for the lecture: graded, oral exam, exercises: ungraded, written | | | | |
| **6** | **Participation requirements**<br>No | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Priv.-Doz. Dr. F. Weichert | | **Faculty in charge**<br>Department of Computer Science | | |

| **Module:** Medical image processing | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 or 9 | **Work load**<br>180 h or 270h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | 2 | Exercise (optional) | T | 3 | 2 |
| **2** | **Language:** English? | | | | |
| **3** | **Content**<br>The capture and processing of images (generally sensor data) with computers and mobile devices is spreading rapidly due to the inexpensive availability of the technical equipment. The subject of the course is methods of digital image analysis. One focus is the classic processing chain of image analysis, which is divided into the parts discretization, image restoration, image enhancement and segmentation. Basic concepts such as the sampling theorem, the Fourier transform and other transformations as well as methods for solving optimization problems are presented. Another focus is the introduction to machine learning methods (deep learning), image compression and 3D computer vision, which are the basis for important applications of digital image processing. | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>- Students have basic knowledge that enables them to recognize and master tasks that can be solved using digital image analysis methods.<br>- Students find their way around the field in such a way that they are able to identify, understand and apply related methods and procedures that go beyond those of the lecture, depending on the task | | | | |
| **5** | **Examination**<br>Coursework: none; Module examination or two partial achievements. If you only take the lecture: graded oral module examination. If the exercises are also completed: two partial achievements, for the lecture: graded, oral exam, exercises: ungraded, written | | | | |
| **6** | **Participation requirements**<br>No | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Priv.-Doz. Dr. F. Weichert | | **Faculty in charge**<br>Department of Computer Science | | |

| **Module:** Seminar - Medical Image and Signal Processing | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 or 9 | **Work load**<br>180 h or 270h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | 2 | Exercise (optional) | T | 3 | 2 |

**2 Language:** English?

**3 Content**

Medical image and signal processing is developing into a key technology in the diagnosis and therapy of various clinical pictures, both through more complex and efficient algorithms and through new imaging and processing hardware. As part of the seminar, relevant concepts and techniques will be examined. The lectures will cover, among other things, current methods of image analysis and pattern recognition for computer-aided diagnostics and therapy, for two- and three-dimensional reconstruction and visualization, as well as numerical and analytical methods for simulating and describing the relevant processes in the context of diagnostics and therapy. In addition, work on experimental and imaging procedures (e.g. MRI) is also discussed. Within the seminar should
- Machine learning methods (e.g. CNNs) for classifying relevant structures or predicting processes,
- Visualization methods for representing static and dynamic processes,
- Techniques for simulating medical and biological processes,
- Concepts for generating realistic models via synthesis or additive manufacturing processes,
- Algorithms for the photorealistic spatial representation of anatomical structures,
- Measurement techniques (e.g. CT, MRT) to determine processes (e.g. flow processes) and anatomical structures be treated as lecture topics

**4 Learning outcome**

After successfully completing the module
- Students can independently review literature on a given topic and grasp and reproduce the essential content.
- The students master key skills for presenting their results, such as the written summary of the research results (literature study) and the presentation of the results.
- Students are enabled to express constructive criticism of the work of colleagues (peer review) and to formulate questions regarding content.

**5 Examination**

The coursework is achieved in the form of a lecture and participation in the discussion of other lectures.

**6 Participation requirements**

No

**7 Module type**

Elective module

| 8 | **Responsible**<br>Priv.-Doz. Dr. F. Weichert | **Faculty in charge**<br>Department of Computer Science |
|---|---|---|

# Subject area Neuroinformatics

| **Module:** Machine Learning - Supervised Methods (NI02) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with integrated exercise, flipped classroom) | L+T | 6 | |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Basics of statistical learning theory, cross-section of the most important machine learning algorithms, concrete problem solving with standard software | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>1. the participants understand the basics of statistical learning theory,<br>2. the participants know the most important algorithms of supervised statistical learning and can apply them to learning problems,<br>3. the participants know the strengths and limitations of different learning methods,<br>4. Participants can use standard machine learning software to solve new problems. | | | | |
| **5** | **Examination**<br>will be announced at the beginning of the event | | | | |
| **6** | **Participation requirements**<br>no | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Prof. Dr. Tobias Glasmachers | | **Faculty in charge**<br>Department of Computational Neuroscience (RUB) | | |

| **Module:** Machine Learning - Evolutionary Algorithms (NI03) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with integrated exercise, flipped classroom) | L+T | 6 | |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Broad overview of optimization methods.<br>Evolutionary optimization methods for black-box optimization methods<br>Algorithmic components for poor conditioning, multimodality, noise, constraints, and multiobjective optimization.<br>Convergence and runtime analysis. | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>a) the participants know the most important classes of direct optimization methods and their algorithmic components,<br>b) participants have a deep understanding of evolutionary algorithms, especially for continuous problems,<br>c) the participants know a number of specific problem difficulties and the associated algorithmic components that address them,<br>d) Participants can carry out elementary runtime analyzes and understand the most important convergence classes<br>e) Participants can implement optimization methods themselves and use them to solve new problems. | | | | |
| 5 | **Examination**<br>will be announced at the beginning of the event | | | | |
| 6 | **Participation requirements**<br>no | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Tobias Glasmachers | **Faculty in charge**<br>Department of Computational Neuroscience (RUB) | | | |

| **Module:** Machine Learning: Unsupervised Methods (NI04) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with integrated exercise, flipped classroom) | L+T | 6 | |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>This course covers a variety of unsupervised methods from machine learning such as principal component analysis, independent component analysis, vector quantization, clustering, Bayesian theory and graphical models. We also briefly discuss reinforcement learning. | | | | |
| 4 | **Learning outcome**<br>After the successful completion of this course the students<br>a) know a number of important unsupervised learning methods,<br>b) can discuss and decide which of the methods are appropriate for a given data set,<br>c) understand the mathematics of these methods,<br>d) can communicate about all this in English. | | | | |
| 5 | **Examination**<br>will be announced at the beginning of the event | | | | |
| 6 | **Participation requirements**<br>The mathematical level of the course is mixed but generally high. The tutorial is almost entirely mathematical. Mathematics required include calculus (functions, derivatives, integrals, differential equations, ...), linear algebra (vectors, matrices, inner product, orthogonal vectors, basis systems, ...), and a bit of probability theory (probabilities, probability densities, Bayes' theorem, ...). | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Laurenz Wiskott | **Faculty in charge**<br>Department of Computer Science (RUB) | | | |

| **Module:** Computational Neuroscience: Neural Dynamics (NI05) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

**1 Module structure**

| No. | Element / Course | Type | Credits | Contact hours per week |
|---|---|---|---|---|
| 1 | Lecture and exercises | L+T | 6 | |

**2 Language:** English

**3 Content**

This course lays the foundations for a neutrally grounded understanding of the fundamental processes in perception, in cognition, and in motor control, that enable intelligent action in the world. The theoretical perspective is aligned with ideas from embodied and situated cognition but embraces concepts of neural representation and aims to reach higher cognition. Neural grounding is provided at the level of populations of neurons in the brain that form strongly recurrent neural networks and are ultimately linked to the sensory and motor surfaces.
The theoretical concepts on which the course is based come from dynamical systems theory. These concepts are used to characterize neural processes in strongly recurrent neural networks as neural dynamic systems, in which stable activation states emerge from the connectivity patterns within neural populations. These connectivity patterns imply that neural populations represent low-dimensional features spaces. This leads to neural dynamic fields of activation as the building blocks of neural neuroscience architectures. Dynamic instabilities induce change of attractor states from which cognitive functions such as detection, change, or selection decisions, working memory, and sequences of processing stages emerge.
Exercises will focus on hands-on simulation experiments, but also involve readings and the writing of short essays on interdisciplinary research topics. Tutorials on mathematical concepts are provided, so that training in calculus and differential equations is useful, but not a prerequisite for the course.

**4 Learning outcome**

- Learning fundamental principles of the neural grounding of perception, action, and cognition. This includes basic notions of coding, population code, forward and recurrent neural networks, neural dynamics, and attractor dynamics.
- Through exposure to knowledge from neuroscience, psychology, cognitive science, and theoretical neuroscience, students experience interdisciplinary discourse and appreciate the need for disciplinary grounding of concepts.
- Through the exercises, students learn to read and write scientific texts in a variety of disciplines. They learn to describe and illustrate mathematical models and their properties.
- Students learn how dynamical systems are used to model neural systems.

**5 Examination**

oral exam

**6 Participation requirements**

no

**7 Module type**

Elective module

| **8** | **Responsible** | **Faculty in charge** |
|---|---|---|
| | Prof. Dr. Gregor Schöner | Department of Computer Science (RUB) |

| **Module:** Machine Learning: Vision and Memory (NI06) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with integrated exercise, flipped classroom) | L | 6 | |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>This lecture covers basic neurobiology and models of self-organization in neural systems, in particular addressing vision (receptive fields, neural maps), and hippocampus (navigation and associative memory). | | | | |
| 4 | **Learning outcome**<br>After the successful completion of this course the students<br>- know basic neurobiological facts about the visual system and the hippocampus,<br>- know a number of related models and methods in computational neuroscience,<br>- understand the mathematics of these methods,<br>- can communicate about all this in English. | | | | |
| 5 | **Examination**<br>will be announced at the beginning of the event | | | | |
| 6 | **Participation requirements**<br>The mathematical level of the course is mixed but generally high. The tutorial is almost entirely mathematical. Mathematics required include calculus (functions, derivatives, integrals, differential equations, ...), linear algebra (vectors, matrices, inner product, orthogonal vectors, basis systems, ...), and a bit of probability theory (probabilities, probability densities, Bayes' theorem, ...). | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Laurenz Wiskott | | **Faculty in charge**<br>Department of Computer Science (RUB) | | |

| **Module:** Autonomous Robotics: Action, Perception and Cognition (NI07) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture and exercises | L+T | 6 | |

**2 Language:** English

**3 Content**

Neural computation is concerned with the discovery of new solutions to technical problems of information processing. These solutions are sought based on analogies with nervous systems and the behavior of organisms. This course focuses on three exemplary problems to illustrate this approach:

- Artificial action (autonomous robotics);
- Artificial perception (robot vision);
- Artificial cognition (simplest cognitive capabilities of autonomous robots such as decision making, scene representation, working memory, sequence generation, behavioral organization).

The main method is nonlinear dynamical systems applied to neural networks, leading to Dynamic Field Theory and neural dynamics.

**4 Learning outcome**

- Students understand the component problems of autonomous robotics and appreciate the multi-disciplinary nature of the field.
- By learning about neural principles of perception, action, and cognition, and relating these to functionalities of artificial cognitive systems, students experience interdisciplinary discourse and appreciate the need for disciplinary grounding of concepts.
- Through the exercises, students learn to read and write technical texts that describe mathematical models and their implementation in numerical simulation.
- Students learn how dynamical systems are used to behavioral systems. They link dynamical systems to established methods in motion planning and control.

**5 Examination**

will be announced at the beginning of the event

**6 Participation requirements**

none

**7 Module type**

Elective module

| 8 | **Responsible** | **Faculty in charge** |
|---|---|---|
| | Prof. Dr. Gregor Schöner | Department of Computer Science (RUB) |

| **Module:** Modeling, simulation and analysis (NI08) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS (every 2 years) | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture and exercises | L+T | 6 | |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>The course deals with methods for modeling and simulating technical systems. In the first part of the lecture, general concepts of modeling and simulation are presented, typical application scenarios are discussed, and the achievable results are worked out. Techniques are then taught to evaluate and improve systems using simulation models. This part includes the presentation of methods for system comparison, experiment planning and optimization of simulation models. Continuous and hybrid simulation models are then introduced. The lecture concludes with methods for increasing the efficiency of simulation through variance reduction techniques and parallel simulation. | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>– Students were introduced to current research in the field of simulation<br>– Students have become familiar with the basic problems and the currently available solution techniques<br>– Students are able to classify the existing methods of simulative model analysis and optimization and use them for concrete applications, with a focus on the discrete and hybrid simulation of technical systems<br>– Students also know the limits of stochastic models<br>– Students have an overview of the areas of application and mathematical problems of continuous simulation | | | | |
| 5 | **Examination**<br>will be announced at the beginning of the event | | | | |
| 6 | **Participation requirements**<br>none | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. P. Buchholz | **Faculty in charge**<br>Department of Computer Science (TU) | | | |

| **Module:** Practical optimization (NI09) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>8 | **Work load**<br>240 h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture and exercises | L+T | 8 | 4+2 |
| 2 | **Language:** English? | | | | |
| 3 | **Content**<br>When optimizing complex systems, especially in engineering sciences, it usually quickly becomes apparent that the range of analytical and exact solution methods is too limited for practice due to idealized requirements. “Practical optimization” therefore deals with solution approaches that have proven themselves for practice-relevant problem classes such as non-convex optimization under the black box scenario, optimization under uncertainty and time-variant problems, multi-criteria optimization and finally symbolic optimization. Methodologically, direct deterministic search methods as well as evolutionary algorithms are used here. Particular attention is paid to the hybridization of optimization procedures with statistical methods: forecast models are used for time-invariant problems, statistical test procedures are used for optimization under uncertainty, and kriging procedures or neural networks are used for function approximation. Other topics include software engineering issues relating to the coupling of optimization procedures and (commercial) simulators as well as the sensible use of parallel hardware. The exercises are intended to actively deal with the solution approaches, whereby existing interfaces to simulators have to be operated using software | | | | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>- Students have gained insight into the problems and analytical structure of the respective problem class and have learned specialized methodological knowledge for the practical solution of such problems<br>- Students know and master practical solution approaches and have the ability to independently work on practical problems<br>- Students have learned to critically assess the results | | | | |
| 5 | **Examination**<br>will be announced at the beginning of the event | | | | |
| 6 | **Participation requirements**<br>no | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. Dr. Günter Rudolph | | **Faculty in charge**<br>Department of Computer Science (TU) | | |

# Subject area Biophysics

| **Module:** Physics of life (**BP12**) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture + Tutorial | L+T | 6 | 4 |
| **2** | **Language: English** | | | | |
| **3** | **Content**<br>i) Thermodynamics, phase transformations and critical phenomena in biology. Role of fluctuations, Landau-Ginzburg, connection to all other areas<br>ii) Mechanics of the cell: elasticity of shells, Helfrich theory, wetting, cell adhesion according to Sackmann, budding line tension.<br>iii) Electrostatics on biopolymers and membranes: Poisson-Boltzmann, Gouy Chapmann, coupling to phase transformations<br>iv) Polymer Theory: Gauss and Flory Chain, Dynamics (Rousse and Zimm), De Gennes, Reptation, Semiflexible Polymer<br>v) Viscoelasticity theory of biopolymer networks/cytoskeleton. Affine networks, scale arguments, rubber plateau, dynamics and elasticity<br>vi) Life at small Reynolds numbers. Microswimmer, reversibility, slender body theory (sperm, bacteria, paramecium, lungs,...)<br>vii) Non-linear phenomena. (coupled) nonlinear oscillators (hearing), solitons, application nerves, heart...<br>viii) Evolution theory | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>- Students can apply physical concepts of hydrodynamics, elasticity theory, thermodynamics/statistics and electrodynamics in an interdisciplinary manner to questions of biological and medical physics (especially) on a mesoscopic and macroscopic scale.<br>- In the exercises, students learned to independently understand problems from the interdisciplinary subject area of biological physics and physiology as physical problems, to solve them and to discuss them in the group. | | | | |
| **5** | **Examination**<br>Graded exam (120 min) or oral exam (30 min), will be announced at the beginning of the course | | | | |
| **6** | **Participation Requirements**<br>No | | | | |
| **7** | **Module type**<br>Elective module/ mandatory module | | | | |
| **8** | **Responsible**<br>Prof. Dr. Matthias Schneider | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Theory of Soft and Biological Matter (PHY633) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per** |
| | 1 | Lecture with exercise | L+T | 6 | 3 + 1 |
| 2 | **Language:** English | | | | |

**3 Content**

Important soft and biological matter systems: colloidal systems, liquid crystals, polymers, fluid interfaces, fluid membranes; cell membrane, DNA, cytoskeleton, proteins, motor proteins, protein filaments.

1. **Statistical physics:**
   virial expansion, phase transitions (MeanField, scale laws).
2. **Molecular interactions:**
   Debye-Hückel theory, van der Waals interaction, DLVO theory, hydrophobic effect, hydrogen bonds, steric interactions.
3. **Polymers:**
   chain models, self-avoidance, polymer solutions, adsorption, rubber elasticity.
4. **Fluid interfaces:**
   surface tension, differential geometry, surfaces of constant curvature, capillary waves, wetting, foams.
5. **Membranes:**
   bending energy, liquid vesicle shapes, thermal fluctuations.
6. **Stochastic dynamics:**
   Brownian motion, diffusion problems, random walk, Markov processes, Langevin equation and Fokker-Planck equation.
7. **Physical and chemical kinetics:**
   thermally activated processes, chemical equilibrium, chemical kinetics, Michaelis-Menten.
8. **Biological physics:**
   molecular motors, filaments, ATP-driven processes.

**4 Learning outcome**

Students will be able to apply modern methods of theoretical physics (from the fields of statistical physics, mechanics, electrodynamics) to systems of soft matter and biological physics in an interdisciplinary way. In the exercises, the students learn to understand problems from the interdisciplinary subject area of Soft Matter as theoretical-physical problems, to solve them and to discuss them in groups.

**5 Examination**

Course work: Exercises Module examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course.

**6 Participation requirements**

no

**7 Module type**

Elective module

| | | |
|---|---|---|
| 8 | **Responsible**<br>Prof. J. Kierfeld | **Faculty in charge**<br>Department of Physics |

| **Module:** Theory of Soft and Biological Matter II (PHY838) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>As needed | **Duration:**<br>1 semester | **Semester:**<br>2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture and exercise | L+T | 5 | 2 + 1 |
| **2** | **Language:** English | | | | |

**3 Course content**

Advanced topics in soft and biological matter: in particular, theoretical models for membranes, cytoskeleton, proteins, motor proteins, protein filaments.

1. **Membranes:**
   bending energy, liquid vesicle shapes, thermal fluctuations.
2. **Stochastic dynamics:**
   Brownian motion, diffusion problems, random walk, Markov processes, Langevin equation and Fokker-Planck equation.
3. **Physical and chemical kinetics:**
   thermally activated processes, chemical equilibrium, chemical kinetics, Michaelis-Menten.
4. **Biological physics:**
   molecular motors, filaments, ATP-driven processes.
5. **Nonlinear dynamics:**
   nonlinear mathematical models biological processes, reaction-diffusion processes, pattern formation, Turing instabilities.

**4 Learning outcome**

Students will be able to apply the modern methods of theoretical physics (from the areas of statistical physics, stochastic dynamics, nonlinear dynamics) to systems of soft matter and biological physics in an interdisciplinary manner. In exercises, students learn to independently grasp problems from the interdisciplinary subject area of soft matter as a theoretical-physical problem, to solve them and to discuss them in the group.

**5 Examination**

Course work: Exercises.
Module examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course.

**6 Participation requirements**

Recommended: Theory of soft and biological matter 1. part

**7 Module type**

Elective module

| | | |
|---|---|---|
| **8** | **Responsible**<br>Prof. J. Kierfeld | **Faculty in charge**<br>Department of Physics |

| **Module:** Soft Matter and Biophysics: Experiment and Theory (PHY713) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1st sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Self-study and own presentation | S | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>The seminar will consist of student presentations on topics related to soft matter and biophysics: Experimental methods and theoretical concepts in soft matter and biophysics, e.g.:<br><br>1. **Soft Matter:**<br>experimental techniques such as small angle X-ray scattering and X-ray reflectivity, theory of colloids (hard spheres), liquid crystals, membranes and vesicles, polymers (DNA), etc.<br>2. **Biophysics:**<br>experimental methods such as X-ray structure analysis and protein crystallization, high-resolution microscopy, theory and simulation of proteins and protein folding, molecular motors, viruses, etc. | | | | |
| 4 | **Learning outcome**<br>Students become familiar with a wide variety of experimental methods and theoretical concepts used in the interdisciplinary field of soft matter and biophysics research. In addition, students also acquire presentation techniques for knowledge transfer and discussion techniques. . | | | | |
| 5 | **Examination**<br>Course achievement: Active participation in the discussions following the lectures.<br>Module examination: Graded own presentation (30min + 15min discussion). | | | | |
| 6 | **Participation requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. J. Kierfeld, Prof. M. Tolan | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Structural Analysis with X-rays (PHY829) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>2 weeks<br>Block course | **Semester:**<br>1st/2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Block course | L | 3 | 2 |
| | 2 | Exercises and self-study | T | 2 | 1 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>1. **Structure of ideal crystals:**<br>description of periodic structures, fundamental lattice types, lattice planes, examples of simple crystal structures.<br>2. **X-ray structure analysis:**<br>diffraction of waves at the crystal, Laue interference function, reciprocal lattice, methods of X-ray structure analysis, structure factor, phase problem, non-ideal crystal structures, amorphous structures, scattering at the surface.<br>3. **Special X-ray techniques:**<br>X-ray reflectometry, small angle X-ray scattering, absorption spectroscopy, fluorescence spectroscopy, X-ray Raman scattering.<br>4. **Modern X-ray sources:**<br>X-ray tube, synchrotron radiation sources, X-ray laser. | | | | |
| 4 | **Learning outcome**<br>Students learn the basic description of crystal structures, the fundamentals of structure elucidation with X-rays and various applications of the corresponding experimental methods. They gain an overview of the different X-ray methods that can be used for the structural elucidation of crystalline and non-crystalline systems. | | | | |
| 5 | **Examination:**<br>Graded written or oral module examination; to be announced at the beginning of the course. | | | | |
| 6 | **Participation Requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dr. C. Sternemann, Dr. M. Paulus | | **Faculty in charge**<br>Department of Physics | | |

# Subject area Applied Physics in Medicine

| **Module:** Applied Physics in Clinical Medicine (PHY7226) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>1. Physics as a duty for the physician (radiation protection, Medical Devices Act)<br>2. Technical devices in diagnostics and therapy<br>3. Brain, eye, ear<br>4. Neck<br>5. Lung<br>6. Heart<br>7. Visceral surgery I (esophagus, gastrointestinal)<br>8. Visceral surgery II (liver, gall bladder, pancreas)<br>9. Trauma surgery<br>10. Orthopedics<br>11. Angiology | | | | |
| **4** | **Learning outcome**<br>Basic knowledge of applied physics in the clinical medicine according to the course content.<br>The seminars are structured so that first the anatomy and physiology, the pathophysiology and then the typical diseases are discussed and to what extent physics is applied in diagnostics and therapy.<br>When possible, particular reference is made to the possible field of activity of the medical physicist. | | | | |
| **5** | **Examination**<br>Written or oral module final examination: the requirements.<br>will be announced by the instructor at the beginning of the course. | | | | |
| **6** | **Participation requirements**<br>no | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dr. A. Schilling (Klinikum Westfalen) | | | **Faculty in charge**<br>Department of Physics | |

| **Module:** Accelerator Physics I (PHY712) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1st sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 4 | 3 |
| | 2 | Exercises | T | 2 | 1 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>1. **Introduction:**<br>physics basics, history, accelerator types.<br>2. **Transverse beam dynamics:**<br>magnets, particle optics, transverse phase space<br>3. **Longitudinal beam dynamics:**<br>high frequency systems, longitudinal phase space<br>4. **Synchrotron radiation:**<br>properties of synchrotron radiation, radiation damping, wigglers and undulators, synchrotron radiation sources. | | | | |
| **4** | **Learning outcome**<br>Students obtain an overview of the physics and technology of particle accelerators that is beneficial not only for a career in accelerator physics, but also for future experimenters at an accelerator. Students learn the essential steps in designing an accelerator or storage ring. They perform beam dynamics calculations as part of exercises, including practice using a scripting language such as Matlab. | | | | |
| **5** | **Examination**<br>Study achievements: Successful completion of the exercises on a regular basis, active Participation in the exercises<br>Module examination: Graded oral examination (30 min) | | | | |
| **6** | **Participation requirements** | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Accelerator Physics II (**PHY812**) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

<table>
<tr><td rowspan="4">1</td><td colspan="5">Module structure</td></tr>
<tr><td>No.</td><td>Element / Course</td><td>Type</td><td>Credits</td><td>Contact hours per week</td></tr>
<tr><td>1</td><td>Lecture</td><td>L</td><td>3</td><td>2</td></tr>
<tr><td>2</td><td>Exercise / Seminar</td><td>T/S</td><td>3</td><td>2</td></tr>
<tr><td>2</td><td colspan="5">Language: English</td></tr>
<tr><td>3</td><td colspan="5">Content<br>Brief review of the basics:<br>Longitudinal and transverse beam dynamics, synchrotron radiation<br>A selection coordinated with students from the following special topics:<br>Superconducting magnets and high-frequency structures, beam diagnostics, ultrashort radiation pulse generation, free-electron laser theory, collective phenomena in storage rings, beam cooling, Hamiltonian beam dynamics, special accelerator facilities (e.g., energy-recovery linear accelerators, spallation sources, neutrino factories), new concepts (e.g., laser-plasma accelerators).<br>Field trip to an out-of-town accelerator laboratory</td></tr>
<tr><td>4</td><td colspan="5">Learning outcome<br>Students learn about several current research topics in the field of accelerator physics, aiming for a balanced mix of theory, experimental physics and accelerator technology. Students will perform calculations on the respective topics in exercises, including practicing the use of a scripting language such as Matlab. The seminar program consists of one lecture per participant, possibly supplemented by guest lectures. In this way, the students practice working independently on a special topic and presenting it in a comprehensible way.</td></tr>
<tr><td>5</td><td colspan="5">Examination<br>Module examination: Graded oral examination (30 min).<br>The following course work must be completed as a prerequisite for admission: Regular successful completion of the exercise tasks, active participation in the exercises, a Seminar presentation (20-30 min)</td></tr>
<tr><td>6</td><td colspan="5">Participation Requirements:<br>Participation in the module Accelerator Physics I.</td></tr>
<tr><td>7</td><td colspan="5">Module type<br>Elective module</td></tr>
<tr><td>8</td><td colspan="2">Responsible<br>Dean of the Department of Physics</td><td colspan="3">Faculty in charge<br>Department of Physics</td></tr>
</table>

| **Module:** Fundamentals of Detector Physics (**PHY825**) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>annually in SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Interactions of charged, neutral particles and of photons with matter, overview of overall detector systems, gas-filled ionization detectors (types and modes of operation, ionization and charge loss, motion in elctr. and magn. field, proportional chambers, drift chambers)<br>Field, proportional chambers, drift chambers, semiconductor detectors (basics, pn-junction and interfaces, types, pixel detectors), scintillation detectors (function, applications), calorimetry (electromagnetic and hadronic, homogeneous and sampling), particle identification, trigger systems, data acquisition systems (DAQ) | | | | |
| 4 | **Learning outcome**<br>Students gain an overview of the various detector designs used in particle physics, medical physics, and other fields. In particular, they learn the relationship between the respective primary interactions of the particles to be detected with the total matter traversed and the fractions exploited by the respective detector design. This leads to an understanding of the respective advantages and disadvantages of the construction types for different application purposes. Furthermore, the students are enabled to work with original literature. | | | | |
| 5 | **Examination**<br>Course credits: none.<br>Module Exam: Graded written or oral examination. | | | | |
| 6 | **Participation Requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics | | | |

| **Module:** Detector systems in particle and medical physics (PHY826) | | | | |
|---|---|---|---|---|
| **Degree program: Physics (M.Sc.)** | | | | |
| **Frequency**<br>in WS | **Duration**<br>1 semester | **Semester**<br>1st sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Different types of detectors used in particle and/or medical physics, e.g. semiconductor and scintillation detectors, X-ray detection systems. Detector systems and components composed of different types, e.g. calorimeters, modern particle physics experiments, PET, CT, etc. | | | | |
| **4** | **Learning outcome**<br>The seminar will deepen the knowledge of the different types of detectors which are used in particle physics and in medical physics. The important lectures on systems and trigger systems allow to understand the interplay of the different detector designs to be understood. The prescribed own lecture leads to a very intensive study of a special topic and also trains competences in the field of scientific literature research and presentation techniques. | | | | |
| **5** | **Examination**<br>Coursework: Active participation in the discussion.<br>Graded module examination: oral presentation on one of the topics of the seminar | | | | |
| **6** | **Participation Requirements**<br>Recommended: Fundamentals of Detector Physics | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Organization**<br>Department of Physics | | |

| **Modules:** Advanced Laboratory Course II: Electronics (PHY845) | | | | |
|---|---|---|---|---|
| **Degree program: Physics (M.Sc.)** | | | | |
| **Frequency**<br>in SS | **Duration**<br>1 semester | **Semester**<br>2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Laboratory course in small groups | P | 6 | 4 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>The students deepen basic concepts of electronics and apply them in practical exercises. The practical covers the areas of analog and digital electronics. | | | | |
| 4 | **Learning outcome**<br>The course introduces the fundamental elements of electronics, together with laboratory experiences. The student will acquire knowledge of the typical building blocks, components and methods of electronics. Using standard examples, he/she will be able to identify and characterize components in circuits. The student will gain expertise in working with real circuits and standard measurement setups. The laboratory experience will allow the student to develop social skills working in teams. | | | | |
| 5 | **Examination**<br>Coursework: Preparation and conduction of laboratory experiments including reports<br>Module examination: Oral examination | | | | |
| 6 | **Participation requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

**Module:** Lasers - Types and Applications (PHY729)

| **Degree Program: Physics (M.Sc.)** | | | | |
|---|---|---|---|---|
| **Frequency:**<br>annual | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Self-study and own presentation | S | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>The seminar consists of sections on the fundamentals of laser processes and on active research with lasers:<br>Laser processes, laser types (solid-state, gas, semiconductor, electron lasers, etc.), generation and application of ultrashort laser pulses, generation and application of extremely narrowband lasers, high-power lasers, lasers for communication and message transmission, lasers in medicine.<br><br>Literature: will be announced/provided in the seminar for the respective topics. | | | | |
| 4 | **Learning outcome**<br>Students learn about current problems in the production and use of lasers. The obligatory individual presentation trains competences in the field of scientific literature research and presentation techniques. Different approaches and working methods provide an overview of research with laser radiation. | | | | |
| 5 | **Examination**<br>Course Credits: Active participation in the discussions following the lectures.<br>Module examination: Graded own presentation on a topic from current research. | | | | |
| 6 | **Participation requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Physical-Chemical Analytics 1a, Applied Spectrometry (PHY7219a) | | | | |
|---|---|---|---|---|
| **Degree program: Physics (M.Sc.)** | | | | |
| **Frequency:** as needed | **Duration:** 1 semester | **Semester:** from 1st sem. | **Credits:** 3 | **Work load:** 90 h |

| 1 | **Module structure** | | | | |
|---|---|---|---|---|---|
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |

**2 Language:** English

**3 Content**

Methods of modern analytics (with in-depth study of spectroscopic methods):

1. **Elemental analysis:**
   atomic absorption spectrometry; atomic emission analysis; X-ray fluorescence analysis; elemental mass spectroscopy.
2. **Molecular analysis:**
   infrared and Raman spectroscopy; NMR spectroscopy; Molecular mass spectrometry, solid state and surface analysis: microbeam analysis with photons, electrons and ions; structural analysis.

**4 Learning outcome**

Students gain an overview of the physical principles of modern analytics and are able to independently develop strategies for solving different analytical problems. They know the most important methods, their performance limits and areas of application. They have acquired the ability to select the most suitable methods in the various fields of application and to critically evaluate their results.

**5 Examination**

Module examination: Graded oral examination

**6 Participation requirements**

**7 Module type**

Elective module

| 8 | **Responsible** | **Faculty in charge** |
|---|---|---|
| | PD J. Franzke | Department of Physics |

| **Module:** Quantum Optics (PHY7214) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1st-3rd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Quantization of the light field, discrete variables, photon statistics, correlation functions and Fock states, continuous variables, Wigner functions and squeezed light, light-matter interaction, rotating-wave approximation, cavity quantum electrodynamics, Jaynes-Cummings model and Rabios oscillations, Mollow triplet and resonance fluorescence, weak measurements, entanglement, causality, and the delayed choice quantum eraser.<br><br>Literature:<br>Mandel/Wolf: Optical Coherence and Quantum Optics,<br>Scully/Zubairy: Quantum Optics,<br>Walls/Milburn: Quantum Optics,<br>W. Schleich: Quantum Optics in Phase Space. | | | | |
| 4 | **Learning outcome**<br>Students learn fundamental effects of quantum optics and the adequate theoretical formalism to describe them. This enables the students to understand original papers independently and provides them with the necessary competence to successfully write theses in the field of experimental quantum optics as well as in the field of the theory of light-matter interaction. | | | | |
| 5 | **Examinations**<br>Module examination: Graded oral module examination (30 min). | | | | |
| 6 | **Participation Requirements:** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Modern Optics (PHY7213) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1st-3rd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Novel methodological developments for light field control and modern optical techniques for spectroscopy and imaging and their application in basic research, materials science and medical physics.<br><br>Literature: will be announced/provided in the seminar for the respective topics. | | | | |
| 4 | **Learning outcome**<br>Students learn about current optical methods and applications. The students work out a delimited research topic on the basis of the original literature and prepare it for a presentation. The prescribed own presentation trains competences in the field of scientific literature research and presentation techniques. In the subsequent discussion, students learn scientific discussion techniques.<br>The breadth of topics gives students an overview of the use of optical processes in both research and industrial applications. | | | | |
| 5 | **Examination**<br>Course Credits: Active participation in the discussions following the lectures.<br>Module examination: Graded own presentation on a topic from current research. | | | | |
| 6 | **Participation requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics | | | |

| **Module:** Advanced Solid State Physics II: Magnetism and Superconductivity (PHY7235) | | | | |
|---|---|---|---|---|
| **Degree program: Physics (M.Sc.)** | | | | |
| **Frequency**<br>in WS | **Duration**<br>1 Semester | **Semester**<br>1st /3rd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>The lecture covers the most important aspects on collective phenomena in modern condensed matter physics, particularly on magnetism and superconductivity, based on the basic knowledge of solid state physics and quantum mechanism. Besides the fundamental properties of magnetically ordered materials and superconductors, the lectures will also cover selected topics of the contemporary research.<br><br>**Magnetism:** magnetic moments, magnetization, dia- and para-magnetism of localized ions and of conduction electrons, exchange interaction, spin-orbit coupling, Zeeman interaction, ferromagnetism, antiferromagnetism, magnetic anisotropy, magnetization dynamics, magnetic excitations, quantum spin dynamics, applications.<br><br>**Superconductivity:** vanishing of electrical resistance, Meissner effect, flux quantization, Type-I superconductors, Type-II superconductors, Ginzburg-Landau theory, Bardeen-Cooper-Schrieffer theory, electromagnetic response, superconducting materials, applications.<br><br>Literature:<br>Kittel, C. Introduction to Solid State Physics (Wiley)<br>Ashcroft, Neil W.; Mermin, N. David. Solid State Physics (Brooks/Cole)<br>Gross, R.; Marx, A. Festkörperphysik (3., akt. Aufl.). (De Gruyter.)<br>Reinhold Kleiner and Werner Buckel, Superconductivity: An Introduction (Wiley-VCH)<br>Michael Tinkham, Introduction to Superconductivity (Dover)<br>James. F. Annett, Superconductivity, Superfluids and Condensates (Oxford)<br>Terry R Orlando, Kevin A. Delin, Foundations of Applied Superconductivity (Addison-Wesley) | | | | |
| 4 | **Learning outcome**<br>The lecture provides a comprehensive view of collective phenomena in condensed matter physics, particularly on magnetism and superconductivity. The aim is to develop an understanding in the fundamental physics and in the working principles behind the applications, for example in the fields of spin-electronics, superconducting devices, or more generally of information and communication technology. | | | | |
| 5 | **Examination**<br>Module exam: oral exam (30 min) | | | | |
| 6 | **Participation Requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Dean of the Department of Physics | | **Faculty of charge**<br>Department of Physics | | |

| **Module:** Advanced Nonlinear Spectroscopic Methods in Solid State Physics (PHY628) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>1. **Linear light-matter interaction:**<br>electric polarization, dielectric tensor, linear optics, linear magneto-optics in magnetic materials (metals and insulators), Drude model, Lorentz model.<br>2. **Optics of metals:**<br>free-electron model, plasmons<br>3. **Optics of insulators and semiconductors:**<br>direct and indirect transitions, excitons,<br>4. **Nonlinear optics:**<br>nonlinear electric polarization, harmonic generation, magnetic generation of harmonics**,** generation of harmonics from excitons.<br>**5. Raman spectroscopy:**<br>spontaneous and induced Raman scattering by phonons and magnons.<br>6. **Time-resolved methods:**<br>pump-probe method, time-resolved SHG and THG, time-resolved Raman spectroscopy. | | | | |
| **4** | **Learning outcome**<br>Students gain insight into the physical principles of the optical properties of different classes of materials. The understanding of traditional and modern spectroscopic methods is complemented by direct examples. | | | | |
| **5** | **Examination**<br>Module examination: Graded oral examination (30 min) | | | | |
| **6** | **Participation Requirements:** | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>D. Bossini, Prof. D. Yakovlev | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Physics on ultrashort time scales (PHY5214) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>as required | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>We discuss together each week a fundamental or recent publication from a well-known scientific journal such as *Science* and *Nature* in the field of **attosecond or X-ray physics.**<br>Even though all of these articles are interesting, they are also typically very compact and, thus, often not easy to understand. Our joint discussion in the Journal Club promises a more pleasant (first?) access to technical literature than the solitary study at home. | | | | |
| 4 | **Learning outcome**<br>At the beginning of the seminar, a student briefly presents the respective article (with slides, on the blackboard, with table presentation), and then the whole group discusses it. The aim is to develop a deeper understanding of the described contexts and to develop an independent approach to the study of technical literature. Scientific questions that are not directly related to the article can also be discussed at any time. For a fruitful discussion, the non-presenting participants should also have studied the article before the seminar. | | | | |
| 5 | **Examination**<br>Module examination: Graded own presentation at the presentation of the publication. | | | | |
| 6 | **Participation requirements**<br>Basic knowledge of optics and laser physics. | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>JProf. W. Helml/Prof. S. Khan | | **Faculty in charge**<br>Department of Physics | | |

# Subject area Physics

| **Module:** Einführung in die Festkörperphysik (PHY521) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (B.Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>9 | **Work load**<br>270 h |

**1 Module structure**

| No. | Element / Course | Type | Credits | Contact hours per |
|---|---|---|---|---|
| 1 | Lecture | L | 6 | 4 |
| 2 | Tutorial | T | 3 | 2 |

| | | |
|---|---|---|
| 2 | **Language:** Deutsch | |
| 3 | **Content**<br>- Fundamentals of solid state physics, with a focus on crystalline systems<br>- Phenomenology, theoretical approaches and experimental techniques<br>- Symmetry and structure<br>- Bonds in the solid<br>- Lattice vibrations and phonons<br>- Free and nearly free electrons: band structures<br>- semiconductor<br>- magnetism<br>- Supraleitung<br>- Synchrotron radiation and applications | |
| 4 | **Learning outcome**<br>After successfully completing the module<br>• Students know the most important substance classes and can use the most important microscopic models to discuss the relevant phenomena<br>• Students have acquired in-depth knowledge of electronic structure and modern methods for calculating it<br>• In the exercises, students learned to describe simple physical systems both formally and verbally and to present solutions by solving problems independently and discussing them in groups<br>• Students learned to check their learning success and measure it against that of their fellow students | |
| 5 | **Examination**<br>graded written exam (180 min) | |
| 6 | **Participation requirements**<br>no | |
| 7 | **Module type**<br>Elective module | |
| 8 | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics |

| **Module:** Statistical Methods of Data Analysis/ SMD B (PHY523b) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1st/3rd sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 2 | Lecture with exercise | L+T | 5 | 2 + 1 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>**From measurement data to physical measurement points and statements**.<br>Parameter estimation, optimization problems, least squares method, maximum likelihood method, numerical fit methods, goodness-of-fit, regularization, confidence intervals and hypothesis testing, parameterization of data, Bayesian methods, methods for solving inverse problems and their evaluation, validation techniques, treatment of systematic errors, acceptance calculation. | | | | |
| 4 | **Learning outcome**<br>Today, data are usually collected electronically. The students learn the appropriate handling of statistical methods for the analysis of moderate to very large amounts of data, following the temporal sequence of a data analysis. The exercises are solved (also) on the computer using current software. In the course, practical competence in data analysis is acquired for the preparation of theses and for later professional practice. | | | | |
| 5 | **Examination**<br>Course Credits: Active participation in the exercises of SMD B.<br>Module examination: written or oral. The form of examination will be announced at the beginning of the semester. | | | | |
| 6 | **Participation Requirements**<br>Favorable: Programming knowledge in a suitable language, e.g. Python;<br>Recommended: Participation in the Toolbox Workshop<br>The SMD A event should be heard before the SMD B event. | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. W. Rhode | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Practical Aspects of Instrumentation (PHY7233) | | | | |
|---|---|---|---|---|
| **Degree program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>By the semester | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3/6/9 | **Work load**<br>90/180/270 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| | 2 | Optional: exercise session | T | 3 | 2 |
| | 3 | Optional: seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>The lecture covers basic principles of instrumentation, electronics and sensor technology. The characterization of instruments, aspects of data acquisition as well as measurement procedures is discussed. Furthermore, applications of instrumentation in specific fields of research, e.g. particle physics, condensed matter physics or medical physics, are presented. Current developments in instrumentation are briefly reported on.<br>The exercise session offers the possibility to discuss concrete details and, if applicable, test the material of the lecture in a laboratory environment.<br>The seminar focuses on the historical development of instrumentation in specific fields of research. Concrete examples for modern instrumentation systems, e.g. in spectroscopy, particle physics or medical imaging, are discussed. | | | | |
| **4** | **Learning outcome**<br>The students acquire basic knowledge of modern instrumentation. They are able to name and explain different sensor and detection principles, and understand the composition of common instrumentation systems. Furthermore, the students acquire skills for the critical reading of the literature and improve their presentation techniques | | | | |
| **5** | **Examination**<br>Module examination (lecture) or module component examinations (lecture and optional exercise session and/or seminar)<br>Course work: Active participation in the lecture and the seminar.<br>Examination: Graded oral examination and, if applicable, graded presentation of about 30 minutes in the seminar; the exercise session is not graded | | | | |
| **6** | **Participation Requirements** | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Computational Physics (**PHY632**) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1. – 3. sem. | **Credits**<br>9 | **Work load**<br>270 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | 2 | Exercise | T | 3 | 2 |
| **2** | **Language:** English | | | | |

**3 Content**

1. **Basic numerical techniques, e.g.:**
   Numerical differentiation, integration, solution of differential equations. Basic numerical linear algebra problems: systems of linear equations and eigenvalue problems.
2. **Specific numerical techniques of physics, e.g.:**
   Nonlinear optimization in many variables, determination of dominant eigenvalues in high-dimensional spaces, variational methods, solution of coupled ordinary differential equations, molecular dynamics simulations, solution of partial differential equations, Monte Carlo simulations and integrations, solution of stochastic differential equations.
3. **Physical application fields, e.g.:**
   Nonlinear dynamics (Poincaré sections, Lyapunov exponents, attractors, bifurcations). Electrodynamics (potential equation). Optics (diffraction). Quantum mechanics (stationary states, variational methods, ground state calculations, time evolution, scattering problems, Hartree-Fock method). Quantum field theory (lattice QFT, functional integrals). Statistical physics (transfer matrix methods, critical points and critical exponents, simulations of many-body systems with molecular dynamics and classical and quantum Monte Carlo methods, stochastic dynamics). Solid state physics (density functional methods, band structure calculations). Particle physics.

Literature:
Press et al: Numerical Recipes
Schnakenberg: Algorithms in Quantum Theory and Statistical Physics
Thijssen: Computational Physics
Gould-Tobochnik: An Introduction to Computer Simulation Methods.

**4 Learning outcome**

Students will be able to apply the modern methods of computer-aided theoretical physics and computer simulation to examples from elementary particle and condensed matter physics. This includes recognizing the numerical problem, choosing the appropriate algorithm, and implementing it in a program using projects as homework assignments. Working on the projects in a team promotes teamwork and project management skills, as well as the graphical preparation and presentation of numerical results.

**5 Examination**

Course achievement: presentation of the exercise projects.
Graded module examination, written or oral (to be announced at the beginning of the course)

**6 Participation Requirements**

**7 Module type**

Elective module/ mandatory module

| | | |
|---|---|---|
| **8** | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics |

| **Module:** Einführung in die Kern- und Elementarteilchenphysik (**PHY522**) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (B.Sc.)** | | | | |
| **Frequency:**<br>WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>9 | **Work load**<br>270 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |
| | 2 | Tutorial | T | 3 | 2 |
| **2** | **Language:** Deutsch | | | | |
| **3** | **Content**<br>Interaction of radiation with matter, detectors in nuclear and particle physics, dosimetry, accelerators;<br>Nuclear physics: properties of nuclei, nuclear models (e.g. droplet model, shell model), nuclear decays, nuclear fusion and fission, nuclear reactors;<br>Particle physics: additive quantum numbers, isospin, quark model, discrete symmetries (including P, CP, and T violation), properties of leptons, quarks, hadrons and gauge bosons, CKM matrix, key experiments, properties of fundamental interactions, overview of the Standard model of particle physics, current research program in particle physics, connection to cosmology. | | | | |
| **4** | **Learning outcome**<br>After successfully completing the module<br>● Students know the basics of nuclear and particle physics and can use quantum mechanics to describe numerous phenomena<br>● Students are familiar with the experimental methods for detecting nuclear and particle reactions and have received an overview of nuclear physics, radioactivity, the basics of nuclear energy, the standard model of particle physics and the current state of research in the field of particle physics<br>● Students have a basic understanding of the structure of matter and its interactions as well as radioactivity<br>● In the exercises, students learned to describe simple physical systems both formally and verbally and to present solutions by solving problems independently and discussing them in groups<br>● Students learned to check their learning success and measure it against that of their fellow students | | | | |
| **5** | **Examination**<br>graded written exam (180 min) | | | | |
| **6** | **Participation requirements**<br>no | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** General Relativity (PHY634) | | | | |
|---|---|---|---|---|
| **Degree Programm: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with exercise | L+T | 6 | 3 + 1 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br><br>Review of special relativity, principles of general relativity, reference frames and equivalence principle, tensor calculus and geometry in curved spaces, gravity and Einstein's field equations, tests of general relativity, Schwarzschild metrics, stellar models, black holes, gravitational waves, outlook on cosmology and quantum gravity.<br><br>Literature:<br>S.M. Carroll: Spacetime and Geometry: Introduction to General Relativity<br>and others given in the lecture. | | | | |
| **4** | **Learning outcome**<br>Students learn how to mathematically understand the space-time structure of curved spaces. They acquire a deeper insight into the physics of gravity and its relation to the structure of spacetime; they learn by example how a theory with measurable consequences emerges from general principles and postulates; they develop and practice the techniques necessary to apply the formalism of general relativity to concrete problems in astrophysics and cosmology. | | | | |
| **5** | **Examination**<br>Course work: Homework<br>Module examination: Graded oral examination (30 min) or written examination (120 min), will be announced at the beginning of the course. | | | | |
| **6** | **Participation requirements** | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Advanced Solid State Physics I: Semiconductors and Light-Matter Interaction (PHY635) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:** in SS | **Duration:** 1 semester | **Semester:** 2nd sem. | **Credits** 6 | **Work load** 150 h |

**1 Module structure**

| No. | Element / Course | Type | Credits | Contact hours per week |
|---|---|---|---|---|
| 1 | Lecture | L | 6 | 4 |

**2 Language:** English

**3 Content**

The lecture covers the most important aspects of the modern physics of crystalline semiconductors and general aspects of the interaction of solids with light. Specifically, the following topics are covered:

1. **Semiconductor Physics:**
   crystal structures, lattice vibrations, electronic band structure of important semiconductor materials, defect states and electrical transport, heterostructures/nanostructures: fabrication and properties, influence of external fields: Stark effect, quantum Hall effect, semiconductor diodes: band diagram and electrical properties
2. **Linear optics:**
   optical properties of dielectrics, semiconductors and heterostructures including semiconductor structures; phonons, plasmons, polarons, excitons, optical Bloch equations; density matrix formalism; strong and ultra-strong light-matter coupling.
3. **Nonlinear optics:**
   nonlinear susceptibility; nonlinear wave equation; phase matching; 3rd and higher order nonlinearities; nonlinear optics of the two-level system.
4. **Fundamentals of quantum optics:**
   quantization of the electromagnetic field; quantum-mechanical states of the light field; coherence.

Literature:
N.W. Ashcroft, N.O. Mermin: "Solid State Physics"
M. Grundmann, “The Physics of Semiconductors: An Introduction Including Nanophysics and Applications”
M. Fox: "Optical Properties of Solids"

**4 Learning outcome**

The lecture opens a comprehensive view of modern semiconductor physics including the most important heterostructures. It also offers insight into the general optical properties of condensed matter in a broad spectral range from microwave radiation to the ultraviolet. The aim is to develop an understanding in particular of collective electron dynamics, excitations of quasiparticles, nonlinear optical processes and basic features of quantum optics.

**5 Examination**

Module exam: oral exam (30 min)

**6 Participation requirements**

**7 Module type**

Elective module

| **8 Responsible** | **Faculty in charge** |
|---|---|
| Dean of the Department of Physics | Department of Physics |

| **Module:** Advanced Quantum Mechanics (PHY631) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Advanced Quantum Mechanics | L | 3 | 2 |
| | 2 | Exercises in Advanced Quantum Mechanics | T | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>(time-dependent) perturbation theory: S-matrix, Fermi's golden rule;<br>Scattering theory: Lippmann-Schwinger, Born cross section<br>Path integrals: classical limit, harmonic oscillator;<br>Relativistic quantum mechanics: Poincare transformers, spinors<br>Klein-Gordon equation<br>Dirac equation: covariance, P,T,C, non-relativistic limit, fine structure.<br>Field quantization, Fock space, photons,<br>Symmetries, SUSY-QM<br><br>Literature:<br>Schwabl: Quantum Mechanics for Advanced Students,<br>Peskin, Schroeder: An Introduction to Quantum Field Theory,<br>L.D. Landau, E.M. Lifshitz: Quantum Mechanics, Vol. III. | | | | |
| **4** | **Learning outcome**<br>Students learn the most important elements of advanced quantum mechanics, as well as the methods for technical handling of questions and calculation of measured quantities. In addition to canonical quantization, the path integral is introduced as an important concept of modern field theory at the harmonic oscillator. Relativistic quantum mechanics is a major focus, here increased emphasis is placed on good mastery and conceptual understanding of the appropriate transformations for objects with spin. Students are introduced to methods as used in current research.<br>In the exercises, students learn to describe simple physical systems both formally-mathematically and verbally and to present solutions by solving problems independently and discussing them in the group. In doing so, they learn to check their learning success and measure it against that of their fellow students. To encourage teamwork, homework is accepted as group work by up to 3 students. | | | | |
| **5** | **Examination**<br>Course achievement: Homework<br>Module examination: Graded written exam (120 min) | | | | |
| **6** | **Participation requirements** | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module** Methods of clinical research (PHY6210) | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 5 | 3 |

**2 Language:** English?

**3 Content**

Connections in clinical research. Methodological, statistical, legal and ethical aspects.

**Classification of studies:** Observational studies (case-control studies, cross-sectional studies, cohort studies), intervention studies (randomized, controlled, double-blind), clinical trial phases.
**Static differentiation of study groups:** Parametric and non-parametric tests.
**Associations of study variables**: correlation (Pearson, Spearman), regression (univariate, multivariate and logistic)
**Risk and prognostic factors**: Odds Ratio, Hazard Ratio, absolute risk, relative risk.
**Accuracy of diagnostic procedures:** Sensitivity, specificity, receiver operating curve (ROC), likelihood ratio (LR+ and LR-).
**Exercise capacity:** Evaluation of maximal and submaximal exercise tests.
**Life quality:** Questionnaires – handling and evaluation.
**Legal and ethical aspects:** Good Clinical Practice (GCP), Ethics Committee, Federal Institute for Drugs and Medical Devices (BfArM).

**4 Learning outcome**

After successfully completing the module
- Students have learned methods that are used in clinical research
- Since medical science involves research on subjects, students also acquire knowledge of legal and ethical aspects
- In the exercises, students learned to independently identify tasks from the field of clinical research as problems, solve them and discuss them in the group.

**5 Examination**

Graded exam (120 minutes) or oral exam (30 minutes), will be announced at the beginning of the event

**6 Participation requirements**

no

**7 Module type**

Elective module

| | | |
|---|---|---|
| **8** | **Responsible**<br>Dr. G Weinreich | **Faculty in charge**<br>Department of Physics |

| **Module:** Applications of Synchrotron Radiation (Lecture) (PHY8211a) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1st-4th sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>The course will cover the following topics:<br>1. **Generation of synchrotron radiation**:<br>operating principle of a storage ring, relativistic description of a charge moving in a magnetic field, insertion devices, X-ray optics and scheme of a beamline.<br>2. **X-ray interaction with matter:**<br>scattering and absorption in the classical approach (Maxwell equations and dumped Lorentz oscillators) and semi-classical approach.<br>3. **Applications of synchrotron radiation:**<br>photoemission techniques (X-ray photoemission spectroscopy and microscopy, angle-resolved photoemission spectroscopy, X-ray photoelectron diffraction, spin polarized photoemission spectroscopy) and their applications, e.g. chemical/structural analysis and study of the electronic properties of the matter with/without spatial resolution. Absorption techniques (X-ray absorption spectroscopy, X-ray magnetic circular dichroism) and their applications, e.g. study of the magnetic and chemical properties of the matter. Diffraction techniques, from crystal and powder. | | | | |
| **4** | **Learning outcome**<br>The aim of the course is to provide a basic knowledge on the main parameters involved in a synchrotron-based experiment, as well as to have an overview on the most important techniques that can be performed, with a special focus on the photoemission-related experiments. | | | | |
| **5** | **Examination**<br>Graded oral examination: | | | | |
| **6** | **Participation requirements** | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dr. G. Zamborlini | | | **Responsible Faculty**<br>Department of Physics | |

| **Module:** Applications of Synchrotron Radiation (Seminar) (PHY8211b) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1st-4th sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |

**3** **Content**

The course will cover the following topics:

1. **Generation of synchrotron radiation**:
   operating principle of a storage ring, relativistic description of a charge moving in a magnetic field, insertion devices, X-ray optics and scheme of a beamline.
2. **X-ray interaction with matter:**
   scattering and absorption in the classical approach (Maxwell equations and dumped Lorentz oscillators) and semi-classical approach.
3. **Applications of synchrotron radiation:**
   photoemission techniques (X-ray photoemission spectroscopy and microscopy, angle-resolved photoemission spectroscopy, X-ray photoelectron diffraction, spin polarized photoemission spectroscopy) and their applications, e.g. chemical/structural analysis and study of the electronic properties of the matter with/without spatial resolution. Absorption techniques (X-ray absorption spectroscopy, X-ray magnetic circular dichroism) and their applications, e.g. study of the magnetic and chemical properties of the matter. Diffraction techniques, from crystal and powder.

**4** **Learning outcome**

The aim of the course is to provide a basic knowledge on the main parameters involved in a synchrotron-based experiment, as well as to have an overview on the most important techniques that can be performed, with a special focus on the photoemission-related experiments.

**5** **Examination**

Graded own presentation

**6** **Participation requirements**

**7** **Module type**

Elective module

| | | |
|---|---|---|
| **8** | **Responsible**<br>Dr. G. Zamborlini | **Responsible Faculty**<br>Department of Physics |

| **Module:** Ethics of the Natural Sciences (PHY7238) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:** in WS | **Duration:** 1 semester | **Semester:** 1st/2 nd sem. | **Credits** 3 | **Work load** 90 h |

**1 Module structure**

| No. | Element / Course | Type | Credits | Contact hours per week |
|---|---|---|---|---|
| 1 | Seminar | S | 3 | 2 |

**2 Language:** English

**3 Content**

1. **Historical positions:**
   Aristotle (foundation of the discussion in the "Nicomachean Ethics"),
   Kant (The Categorical Imperative in the Metaphysics of Morals and Critique of Practical Reason),
   Schopenhauer (Natural Science and Ethics in the "World as Will and Imagination"),
   Lange (Ethics and Materialism in the "History of Materialism).
2. **Foundations of the current discussion:**
   Günther Anders (The Antiquity of Man),
   Hans Jonas ("The Principle of Responsibility"; "Technology, Medicine and Ethics")
3. **Physics in War:**
   The Farmhall Protocols (Bernstein, "Hilter's Uranium Club"),
   Navasky,
   Ethical Function of War ("Report from Iron Mountain"),
   Robert Jungk ("Brighter than a Thousand Suns").
4. **Special topics on ethical responsibility in medicine and neuroscience:** e.g.
   distribution problems concerning medical technology resources (devices, drugs);
   switching off devices?
   Prolonging life artificially?
   Organ transplantation/brain death criterion?
   Preimplantation diagnostics?
   Brain doping?

Literature:
Dieter Sturma, Bert Heinrichs (eds.) (2015) Handbuch Bioethik.
Metzler; Biller-Andorno, N., Monteverde, S., Krones, T., Eichinger, T. (eds.) Medizinethik. Springer;
Armin Grunwald (ed.): Handbuch Technikethik (2013) Metzler;
Stoecker, Ralf, Neuhäuser, Christian, Raters, Marie-Luise (eds.); Handbuch angewandte Ethik (2011) Metzler;
Europäische Enzyklopädie zu Philosophie und Wissenschaften, Meiner (1990),
further resources: material of the English Ethics Council, DRZE (English Reference Center for Ethics in the Life Sciences), etc.

**4 Learning outcome**

Via self-study on their individual presentation and by attending their peer´s presentations and participating in accompanying discussions, the students acquire a deeper knowledge of the justification of basic positions of ethics and their possibility of application with regard to decision-making problems in natural science or technically induced problems. In addition, the students will acquire the ability to work out the content of specialist texts from the field of philosophy and to identify the core questions relevant to physics or natural sciences and to relate them to the current social situation.
The students learn to familiarize themselves with a complex field independently and to present the essential contents in a comprehensive way. They gain knowledge about modern presentation techniques and how to use them.
They learn to defend their point of view in a scientific discussion.

**5 Examination**

Course achievement: Seminar presentation
Module exam: written or oral; will be announced at the beginning of the course.

**6 Participation requirements**

**7 Module type**

Elective module

| **8** | **Responsible** Prof. W. Rhode | **Faculty in charge** Department of Physics |
|---|---|---|

| **Module:** Machine Learning for Physicists (PHY626) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>4 | **Work load**<br>120 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module Structure:** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture with Excercise | L +T | 8 | 1 + 1 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Different methods and applications of machine learning will be presented in order to be directly used by the students in practical exercises. The focus is on deep learning methods, such as deep neural networks (DNNs), convolutional neural networks (CNNs) and feedback neural networks (RNNs).<br><br>Exercises are conducted in Jupyter notebooks, and modern software libraries such as Keras, Tensorflow, and Scikit-Learn are used. | | | | |
| **4** | **Learning outcome**<br>Participants learn to apply modern machine learning methods to given problems. The methods learned are then applied to a data analysis problem posed by themselves and both the solution and the results are documented in a project report. | | | | |
| **5** | **Examination**<br>Course work: work on the exercises and presentation of the solutions<br>Module exam: graded project report | | | | |
| **6** | **Participation Requirements**<br>Basic knowledge in Python, desirable is the lecture 'Statistical Methods of Data Analysis'. | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics | | | |

| **Module:** Applications of Machine Learning in Medical Physics (PHY6211) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>in WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

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|---|---|---|---|---|---|
| **1** | **Module Structure:** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>Machine learning has been increasingly used in many areas of medicine for years and even has the potential to change them completely. Already today, machine learning methods are of great importance, for example, in diagnostics with the help of imaging procedures. There, machine learning methods help physicians to evaluate the highly complex data in order to make a diagnosis more precisely and faster. But machine learning can also be used efficiently in other areas, such as therapy planning, treatment or even in the development of effective drugs, not only to save costs and time, but ultimately to provide patients with the best possible care.<br>In this seminar, you will first get an overview of the diverse applications of machine learning in medicine. In addition, you will scientifically research a selected topic, gain a deeper insight and understanding, and clearly prepare and present it as a lecture. The central focus of these seminar lectures is on the medical-physical applications, less on the technical aspects of machine learning.<br>In addition to the seminar lectures, we prepare short lecture inserts in which we take a closer look at the technical aspects of machine learning in the respective applications and explain them without any necessary prior knowledge. | | | | |
| **4** | **Learning outcome**<br>The participants get an overview of current topics in medicine, in which modern machine learning methods are used. You will learn how to research a scientific topic and present it to an audience in a comprehensible lecture. In addition, you will gain insights into how modern machine learning algorithms work. | | | | |
| **5** | **Examination**<br>Course Credits: Active participation in the discussions during the seminar hours.<br>Module examination: Graded, independently researched and elaborated seminar presentation. | | | | |
| **6** | **Participation requirements**<br>Basic knowledge in medical physics, desirable is the lecture 'Statistical Methods of Data Analysis'. | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Dean of Department of Physics | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Introduction to Optical Properties of Solids (PHY725) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (B.Sc/ M.Sc.)** | | | | |
| **Frequency:**<br>irregular | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module Structure:** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 3 | 2 |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>**Classical propagation of light**: Propagation of light in a dense optical medium, the dipole oscillator model (Lorentz oscillator), the Kramers-Krönig relationships, dispersion, optical anisotropy: birefringence<br>**Absorption**: Interband transitions, band edge absorption in direct gap semiconductors. band edge absorption in indirect gap semiconductors, interband absorption above the band edge<br>**Luminescence:** light emission in solids, photoluminescence, electroluminescence<br>**Excitons**: the concept of excitons, free excitons (Mott–Wannier), free excitons in external fields, free excitons at high densities, tightly bound (Frenkel) excitons<br>**Phonons**: infrared active phonons, infrared reflectivity and absorption in polar solids, polaritons, polarons, Raman scattering, Brillouin<br>**Semiconductor quantum wells**: Quantum confined structures, electronic levels, optical absorption and excitons, the quantum confined Stark effect, optical emission, intersubband transitions<br>**Literature**: C. Klingshirn, Semiconductor Optics, P. Yu and M. Cardona, Fundamentals of Semiconductors; M. Fox, Optical properties of Solids; J. Shah, Ultrafast Spectroscopy of Semiconductors and their Nanostructures. | | | | |
| 4 | **Learning outcome**<br>Students will gain insight into the physical principles of optical properties of different classes of materials by learning basic experimental methods of solid state spectroscopy and their application possibilities in basic research and industry. The lecture ties in with fundamental physics problems and shows students their relevance for modern applications. The understanding of traditional and modern spectroscopic methods is complemented by direct examples | | | | |
| 5 | **Examination**<br>Graded oral exam (30min) | | | | |
| 6 | **Participation requirements**<br>Basic knowledge in Solid state physics and electromagnetism. | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. M. Betz | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Superconducting Technology applied to particle accelerators (PHY7228) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>In WS | **Duration:**<br>2 weeks | **Semester:**<br>1st sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Seminar | S | 3 | Block course |
| 2 | **Language:** English | | | | |
| 3 | **Content**<br>Along the seminar the principles and the application of superconducting radio frequency (SRF) technologies to the operation particle accelerators will be studied. To this end the key topics will be introduced by means of a lecture (superconductivity, SRF cavities, RF losses, limits of normal conducting cavities vs superconducting systems, loss mechanisms, ...). In addition, the students will complement the lectures with their own research on a related proposed topic to be presented by the end of the seminar. In order to prepare this presentation additional material such as scientific papers or presentations will be provided. | | | | |
| 4 | **Learning outcome**<br>The participants will carry out independent research on the suggested topic in order to complete the material taught during the seminar. This work will be presented to the other participants and actively discussed. | | | | |
| 5 | **Examination**<br>Course achievements: Active participation in the discussions following the lectures.<br>Module examination: Graded own presentation. | | | | |
| 6 | **Participation requirements** | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. A. Velez Saiz | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Magnetism Lecture (PHY5210L) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>annually | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>6 | **Work load**<br>180 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per week** |
| | 1 | Lecture | L | 6 | 4 |

| | |
|---|---|
| **2** | **Language:** English |
| **3** | **Content**<br>1. **Basic concepts and building blocks of magnetism:**<br>magnetic moments, magnetic fields, magnetic susceptibility, classification of magnetic materials.<br>2. **Magnetism of atoms/ions and localized magnetic moments:**<br>atomic diamagnetism, atomic paramagnetism, influence of crystal field in solids.<br>3. **Magnetism of conduction electrons:**<br>Landau Diamagnetism, Pauli Paramagnetism, Band Ferromagnetism.<br>4. **Exchange interaction:**<br>direct and indirect exchange, super exchange, double exchange, RKKY interaction. Heisenberg model and Hubbard model for the description of magnetically ordered materials, magnetic order structures and phase transitions.<br>5. **Collective magnetism:**<br>ferromagnetism, antiferromagnetism, ferrimagnetism, magnetic anisotropy, magnetic domain, spin waves, and stoner excitations. |
| **4** | **Learning outcome**<br>Students gain insight into the physical principles of the description of magnetic materials, and into the most important magnetic phenomena. They will be able to apply these concepts to concrete physical situations; for example, they will be able to understand the operation of many applications in the field of information and communication technology. |
| **5** | **Examination**<br>Module examination: Graded oral examination (30 min) |
| **6** | **Participation requirements** |
| **7** | **Module type**<br>Elective module |
| **8** | **Responsible**<br>Prof. M. Cinchetti<br><br>**Faculty in charge**<br>Department of Physics |

| **Module:** Magnetism Seminar (PHY5210S) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>every semester | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>60 h |

| | | | | | |
|---|---|---|---|---|---|
| **1** | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Conta** |
| | 1 | Seminar | S | 3 | 2 |
| **2** | **Language:** English | | | | |
| **3** | **Content**<br>The seminar will include lectures on various topics relevant to current research in magnetism. Among others: Measurement methods, materials, and technologically relevant effects. | | | | |
| **4** | **Learning outcome**<br>The seminar is intended as a supplement to the lecture Magnetism. Students will gain insight into the physical principles of the description of magnetic materials and into the most important magnetic phenomena. They will be able to apply these concepts to concrete physical situations, especially in areas that are currently the focus of research in magnetism. For example, they can understand the operation of many applications in the field of information and communication technology. | | | | |
| **5** | **Examination**<br>Module examination: own oral presentation | | | | |
| **6** | **Participation requirements**<br>In parallel in participation in the lecture Magnetism PHY5210L. | | | | |
| **7** | **Module type**<br>Elective module | | | | |
| **8** | **Responsible**<br>Prof. M. Cinchetti | **Faculty in charge**<br>Department of Physics | | | |

| **Module:** Physics on ultrashort time scales (PHY5214) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>as required | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>3 | **Work load**<br>90 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per** |
| | 1 | Seminar | S | 3 | 2 |

| | |
|---|---|
| 2 | **Language:** English |
| 3 | **Content**<br>We discuss together each week a fundamental or recent publication from a well-known scientific journal such as *Science* and *Nature* in the field of **attosecond or X-ray physics.**<br>Even though all of these articles are interesting, they are also typically very compact and, thus, often not easy to understand. Our joint discussion in the Journal Club promises a more pleasant (first?) access to technical literature than the solitary study at home. |
| 4 | **Learning outcome**<br>At the beginning of the seminar, a student briefly presents the respective article (with slides, on the blackboard, with table presentation), and then the whole group discusses it. The aim is to develop a deeper understanding of the described contexts and to develop an independent approach to the study of technical literature. Scientific questions that are not directly related to the article can also be discussed at any time. For a fruitful discussion, the non-presenting participants should also have studied the article before the seminar. |
| 5 | **Examination**<br>Module examination: Graded own presentation at the presentation of the publication. |
| 6 | **Participation requirements**<br>Basic knowledge of optics and laser physics. |
| 7 | **Module type**<br>Elective module |

| | | |
|---|---|---|
| 8 | **Responsible**<br>JProf. W. Helml/Prof. S. Khan | **Faculty in charge**<br>Department of Physics |

| **Module:** Halbleiterphysik (**PHY6213**) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (B.Sc.)** | | | | |
| **Frequency:**<br>as required in SS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

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|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per** |
| | 1 | Lecture | L | 5 | 3 |
| 2 | **Language:** Deutsch | | | | |
| 3 | **Content**<br>The lecture covers the most important aspects of the physics of crystalline semiconductors. In addition some central semiconductor devices are discussed. Specifically, the following topics are covered:<br><br>Semiconductors: crystal structures, lattice vibrations<br>Electronic band structure of important semiconductor materials<br>Defect states and electrical transport<br>Optical properties of semiconductors<br>Heterostructures/nanostructures: production and properties<br>Influence of external fields: Stark effect, quantum Hall effect<br>Semiconductor diodes: Band diagram and electrical properties<br>Optoelectronic components: photodiodes, LEDs, semiconductor lasers<br>Bipolar and field-effect transistors<br><br>The lecture is based on the book: M. Grundmann, The Physics of Semiconductors: An Introduction Including Nanophysics and Applications | | | | |
| 4 | **Learning outcome**<br>Students will be able to apply the concepts of modern semiconductor physics to understand the operation of modern semiconductor devices and the physics of semiconductor nanostructures.<br>nanostructures. In addition, students learn concepts to describe the properties of semiconductor heterostructures and to solve problems in semiconductor physics independently. | | | | |
| 5 | **Examination**<br>Graded oral exam (30min) | | | | |
| 6 | **Participation requirements**<br>Basic knowledge of Solid state physics | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>Prof. M. Betz | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Photovoltaics (PHY5216) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M.Sc.)** | | | | |
| **Frequency:**<br>as needed in WS | **Duration:**<br>1 semester | **Semester:**<br>1st sem. | **Credits**<br>3 | **Work load**<br>90 h |

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|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per** |
| | 1 | Seminar | S | 3 | 2 |
| 2 | **Language:** English | | | | |

**3 Content**

The seminar deals with the physical fundamentals of photovoltaics. In addition to these fundamentals, methods of analysis and optimization of photovoltaic systems as well as technical implementation are discussed. Especially for students not familiar with the subject, lectures on current topics currently discussed in politics such as smart grids will also be offered. Specifically, it is planned to cover the following topics:

- Optical properties of conventional semiconductors
- Doping, p-n and p-i-n transitions
- solar radiation, Schottky-Queisser limit
- Design of real solar cells, optimization of the fill factor
- Multi-junction solar cells
- Coatings and nanostructuring: optimizing efficiency
- Solar cells from organic semiconductors
- novel solar cells: Thin film solar cells, perovskites
- commercial aspects of photovoltaics
- Challenges and opportunities of integrating solar power into the existing power grid infrastructure

**4 Learning outcome**

Students apply the concepts of modern semiconductor physics to understand the operation of modern solar cells and their optimization. These topics are embedded in the context of sustainable technologies and renewable forms of energy.

**5 Examination**

Module examination: graded oral seminar presentation

**6 Participation requirements**

**7 Module type**

Elective module

| | | |
|---|---|---|
| 8 | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics |

| **Module:** Streumethoden in der Festkörperphysik (**PHY5217**) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (B.Sc.)** | | | | |
| **Frequency:**<br>as required in WS | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **No.** | **Element / Course** | **Type** | **Credits** | **Contact hours per** |
| | 1 | Lecture | L | 5 | 2 |
| 2 | **Language:** Deutsch | | | | |
| 3 | **Content**<br>The lecture covers the most important aspects of the physics of crystalline semiconductors. In addition some central semiconductor devices are discussed. Specifically, the following topics are covered:<br>1. scattering: repetition<br>2. generation of synchrotron radiation<br>3. x-ray scattering: basics<br>4. x-ray scattering at surfaces and interfaces<br>5. x-ray reflectivity<br>6. x-ray absorption spectroscopy<br>7. free electron lasers<br>8. generation of neutrons<br>9. special features of neutron scattering and comparison with X-ray scattering<br>10. small angle scattering with neutrons and X-rays<br>11. inelastic neutron and X-ray scattering<br><br>The lecture is based on the books:<br>Elements of modern X-ray physics, J Als-Nielsen, D McMorrow<br>Introduction to the Theory of Thermal Neutron Scattering, G. L. Squires<br>X-ray and neutron reflectivity: principles and applications:J Daillant, A Gibaud<br>X-ray scattering from soft-matter thin films: M Tolan<br>X-Ray Diffraction Modern Experimental Techniques: Oliver Seeck, Bridget Murphy | | | | |
| 4 | **Learning outcome**<br>Students will be able to apply the concepts of modern scattering methods to understand how modern X-ray and neutron scattering methods work in the physics of solids.<br>In addition, students learn concepts to describe the properties of scattering methods and to use them to solve problems in solid state physics. | | | | |
| 5 | **Examination**<br>Graded oral exam | | | | |
| 6 | **Participation requirements**<br>Basic knowledge of Solid state physics | | | | |
| 7 | **Module type**<br>Elective module | | | | |
| 8 | **Responsible**<br>PD Dr. Bridget Murphy | | **Faculty in charge**<br>Department of Physics | | |

| **Module:** Instruments of Modern Physics (PHY421) | | | | |
|---|---|---|---|---|
| **Degree Program: Physics (M. Sc.)** | | | | |
| **Frequency:**<br>As needed | **Duration:**<br>1 semester | **Semester:**<br>1st/2nd sem. | **Credits**<br>5 | **Work load**<br>150 h |

**1 Module structure**

| No. | Element / Course | Type | Credits | Contact hours |
|---|---|---|---|---|
| 1 | Lecture + Tutorial | L + T | 5 | 3 |

**2 Language:** English

**3 Content**

1. **Introduction:**
   Review of electrodynamics and special relativity, light and particle optics, Signal processing, introduction to programming (for some practice problems).
2. **Sources of electromagnetic radiation:**
   Black body, discharge lamps, laser systems, X-ray tubes, synchrotron radiation sources, free-electron lasers, optical laboratory equipment.
3. **Sources of particle radiation:**
   Cosmic rays, radioactive preparations, accelerators, and storage rings.
4. **Particle detectors:**
   Interaction of radiation with matter, ionization chambers, semiconductor detectors, photomultipliers, scintillators, Cherenkov effect, and transition radiation.
5. **Examples of detection techniques and applications:**
   Detectors in particle and astroparticle physics, gravitational wave detectors, scanning probe microscopes, imaging in medical physics.
6. **Other instruments:**
   Electrical measuring instruments, atomic clocks, superconducting magnets, vacuum technology

**4 Learning outcome**

Students are provided with an overview of instruments and experimental techniques that they may encounter during their studies as well as in their professional practice in a physics laboratory. Emphasis is placed on radiation sources and detectors, but other instruments and digital processing of electrical signals are also addressed. Exercises will include questions testing basic understanding, simple calculations, and simulations using a scripting language (Matlab or Python). Programming skills are not a prerequisite, but will be learned during the exercises through practical application to physical problems.

**5 Examination**

Graded oral module exam (30 min).
Admission requirements: Regular and active participation in the exercises as well as successful completion of the exercises. Details will be announced at the beginning of the lecture.

**6 Participation Requirements**

**7 Module type**

Elective module

**8**

| **Responsible** | **Faculty in charge** |
|---|---|
| Prof. Shaukat Khan | Department of Physics |

# Modules in the research phase

| **Module:** Research Internship | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>every semester | **Duration:**<br>1 semester | **Semester:**<br>3rd sem. | **Credits**<br>15 | **Work load**<br>450 h |

| | | |
|---|---|---|
| 1 | **Module structure**<br>Research internship | |
| 2 | **Language:** English | |
| 3 | **Content**<br>Literature research<br>Familiarization with theoretical procedures or experimental procedures<br>Discussion of problems of current research<br>Preparation of a short (approx. 5 p.) report or presentation<br><br>Literature:<br>Current literature on the respective research area<br>In addition, e.g.<br>Ascheron, Kickuth: Make Your Mark in Science,<br>Alley: The Craft of Scientific Presentation,<br>Alley: The Craft of Scientific Writing. | |
| 4 | **Learning outcome**<br>Students will be able to work independently in a current area of research with the associated experimental or theoretical methods. The students can summarize their work in a report. In addition to the technical deepening, the students have further developed their written presentation skills as well as their media skills and communication skills. | |
| 5 | **Examination** | |
| 6 | **Participation requirements** | |
| 7 | **Module type**<br>Mandatory module | |
| 8 | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics |

| **Module:** Master's thesis | | | | |
|---|---|---|---|---|
| **Degree Program: Master Medical Physics and Physics of Living Systems (M. Sc.)** | | | | |
| **Frequency:**<br>every semester | **Duration:**<br>6 months | **Semester:**<br>4th Sem. | **Credits**<br>30 | **Work load**<br>900 h |

| | | |
|---|---|---|
| 1 | **Module structure**<br>Supervised research | |
| 2 | **Language:** English | |
| 3 | **Content**<br>Work on a current scientific problem in experimental or theoretical medical or bio-physics in an international research environment and final presentation of the results.<br><br>Literature:<br>Monographs, review articles and original publications on the respective scientific problem. | |
| 4 | **Learning outcome**<br>The students are able to work independently on a current scientific project in an international research environment in accordance with a project plan they have developed, i.e. carry out the corresponding experiments or calculations. In addition to the technical competence required for the research project, the students will have developed their methodological competence, team competence, communication competence, oral presentation skills, self-competence (ability to work under pressure, flexibility, time management) and often also intercultural competence. | |
| 5 | **Examination** | |
| 6 | **Participation requirements**<br>Module "Research Internship" | |
| 7 | **Module type**<br>Mandatory module | |
| 8 | **Responsible**<br>Dean of the Department of Physics | **Faculty in charge**<br>Department of Physics |