UNIVERSITÄT
LEIPZIG

Faculty of Physics and
Earth System Sciences

Course Program

Bachelor of Science

IPSP Honours (4 years)

International Physics Study Program

For students enrolled between in winter semester 2022/23 or later
(version of 1st April 2024)

This English translation is intended to allow English-speaking readers a better understanding of the Examination and Study Regulations. It is solely for information purposes – only the official German version is legally binding. Please check the Official Bulletins of Leipzig University for the official study and examination regulations and module descriptions.

1 Study Plan and Course Program

1.1 Study Plan – Bachelor of Science IPSP Honours (4 years)

The following plans and overviews refer to the study documents that are valid for students **starting at winter semester 2022/23 (1st October 2022) or later**. The addon 'Honours' refers to the 4 years regular study time – 240 ECTS are to be achieved for successful graduation.

	Fundamentals (compulsory area)				Electives*
Semester	Theoretical Physics (TP)	Experimental Physics (EP)	Labs	Mathematics (MA)	Non-Physics / Physics / Seminar
1	TP1 – Classical Mechanics 1 **8 CP** / 4+2 SWS	EP1 – Mechanics **8 CP** / 4+2 SWS		MA1 – Mathematics 1 **9 CP** / 4+2 SWS	Non-Physics Electives **5 CP**
2	TP2 – Electro-dynamics 1 **8 CP** / 4+2 SWS	EP2 – Thermo- and Electrodynamics **8 CP** / 4+2 SWS	Introduction to Computer-based Physical Modelling **5 CP** / 2+2 SWS	MA2 – Mathematics 2 **9 CP** / 4+2 SWS	
3	TP3 – Classical Mechanics 2 & Electrodynamics 2 **8 CP** / 4+2 SWS	EP3 – Electromagn. waves / Foundations of Quantum Physics **8 CP** / 4+2 SWS	General Physics Laboratory 1 **5 CP** / 4 SWS	MA3 – Mathematics 3 **9 CP** / 4+2 SWS	
4	TP4 – Quantum Mechanics **8 CP** / 4+2 SWS	EP4 – Atomic and Molecular Physics **7 CP** / 4+2 SWS	General Physics Laboratory 2 **5 CP** / 4 SWS	Order of Magnitude Physics **5 CP** / 2+2 SWS	Non-Physics Electives **5 CP**
5	TP5 – Statistical Physics **8 CP** / 4+2 SWS	EP5 – Soft Matter Physics **7 CP** / 4+2 SWS			Non-Physics / Physics Electives **15 CP**
6		EP6 – Solid State Physics **7 CP** / 4+2 SWS	Advanced Departmental Lab **8 CP** / 6 SWS		Non-Physics / Physics Electives **5-15 CP**
	Electives TP (1 of 2) and EP (1 of 2)*				
		Adv. Soft Matter and Biological Physics **10 CP** / 4+2+1 SWS			
7	Advanced Quantum Mechanics **10 CP** / 4+2 SWS	Advanced Solid State Physics **10 CP** / 4+2+1 SWS			Physics Electives / Advanced Seminar **10-30 CP**
8	Advanced Statistical Physics **10 CP** / 4+2 SWS		Bachelor's thesis **10 CP**	Bachelor's Thesis Colloquium **5 CP** / 1 SWS	Physics Electives / Advanced Seminar **5-15 CP**

CP – credit points (equal to ECTS points); **SWS** – lecture hours per week (usually lecture/lab + seminar or exercises)

* Electives totalling 85 CP: 10 CP Advanced TP, 10 CP Advanced EP, 5 CP Advanced Seminar, 20 CP Non-Physics Electives, 40 CP Physics Electives (up to 25 CP from introduction area, at least 15 CP from deepening area); the recommended CP distribution in semesters 6-8 to complete 30 CP per semester depends on the individual choice of modules

The fundamental modules are obligatory. Teaching content and goals are defined more or less generically in physics programs at German universities. They have arisen from the historical development of physics and thus have a historically developed relationship to each other in terms of content. The physics education at Leipzig University sets equal focus on the understanding of fundamentals in natural science by phenomenological and experimental as well as by theoretical and conceptual approaches.

It is advisable to follow the sequence of the individual modules; however, the modules are accessible and comprehensible independently of each other and even if the sequence of studies is altered. The physics labs are coordinated with the contents of the lectures in Experimental Physics and extend them by learning practical, metrological and data analytical skills.

The elective modules cover 85 CP and are divided into: advanced theoretical physics (10 CP; advanced quantum mechanics or statistical physics), advanced experimental physics (10 CP; advanced soft matter or solid state physics), advanced seminar (5 CP), non-physics elective area (20 CP) and physics-related modules (40 CP).

The non-physics electives comprise 20 CP and contain modules with interdisciplinary topics. In this area, modules of up to 10 CP can be chosen from the entire range of modules offered by Leipzig University (provided the teacher responsible for the module agrees), e.g., language or key qualification modules.

The physics-related electives (40 CP) contain modules for introduction into a specialization (of which 25 CP can be completed) and a deepening area (of which 15 CP need to be completed). The topics cover modules on fundamentals and physics research, e.g. in Semiconductor Physics, Photonics and Quantum Technology, Soft-Matter Physics, Spin Resonance, Magnetism, Materials Science, Quantum Field Theory, Statistical Physics, Complex Systems, Relativity, Mathematical Physics or Astrophysics.

1.2 Course Table

Semester	Module Number	Module Title	CP
1 – 8		***Fundamental Modules (Compulsory Area)***	***140***
1	10-PHY-BIMA1	Mathematics 1 – Linear Algebra and Calculus of Functions of One Variable	9
1	12-PHY-BIEP1	Experimental Physics 1 – Mechanics	8
1	12-PHY-BIPTP1	Theoretical Physics 1 – Classical Mechanics 1	8
2	10-PHY-BIMA2	Mathematics 2 – Calculus of Functions of More Than One Variable	9
2	12-PHY-BIEP2	Experimental Physics 2 – Thermo- and Electro-dynamics	8
2	12-PHY-BIPTP2	Theoretical Physics 2 – Electrodynamics 1	8
2	12-PHY-BWMS	Introduction to Computer-based Physical Modelling	5
3	10-PHY-BIMA3	Mathematics 3 – Vector Calculus and Partial Differential Equations	9
3	12-PHY-BIEP3	Experimental Physics 3 – Electromagnetic Waves and Foundations of Quantum Physics	8
3	12-PHY-BIGP1	General Physics Laboratory 1	5
3	12-PHY-BIPTP3	Theoretical Physics 3 – Classical Mechanics 2 and Electrodynamics 2	8
4	12-PHY-BIEP4	Experimental Physics 4 – Atomic and Molecular Physics	7
4	12-PHY-BIPGP2	General Physics Laboratory 2	5
4	12-PHY-BIPTP4	Theoretical Physics 4 – Quantum Mechanics	8
4	12-PHY-BIOMP	Order of Magnitude Physics	5
5	12-PHY-BIEP5	Experimental Physics 5 – Soft Matter Physics	7
5	12-PHY-BIPTP5	Theoretical Physics 5 – Statistical Physics	8
6	12-PHY-BIPEP5	Experimental Physics 6 – Solid State Physics	7
6	12-PHY-BIFP	Advanced Departmental Lab	8
6 – 7		***Elective – Advanced Experimental Physics***	***10***
6	12-PHY-MWPASM	Advanced Soft Matter and Biological Physics	10
7	12-PHY-MWPE1	Advanced Solid State Physics	10
7 – 8		***Elective – Advanced Theoretical Physics***	***10***
7	12-PHY-MWPT1	Advanced Quantum Mechanics	10
8	12-PHY-MWPT2	Advanced Statistical Physics	10
7 – 8		***Elective – Advanced Seminar***	***5***
7/8	12-PHY-MWPSKM	Specialized Topics of Solid State Physics	5
7/8	12-PHY-MWPSWM	Specialized Topics of Soft Matter Physics	5
7/8	12-PHY-MWPSMP	Specialized Topics of Theoretical and Mathematical Physics	5
7/8	12-PHY-MWPSTP	Specialized Topics of Theoretical Physics	5
1, 4 – 6		***Non-Physics Electives***	***20***
1	12-PHY-BIPC	Introduction to Chemistry	5
4	12-PHY-BWNUM	Numerical Methods in Physics	5
5/6/7/8	12-PHY-BIEPP	External Project Oriented Course –	5

		Subject-related Key Qualification	
4/6/8	12-SQM-63	Women in STEM	5
1/5/7	12-SQM-64 *or*	Sustainable Development - Risk Assessment, Methods and Models# *or*	5
5/7	12-PHY-BMWBNE1	Action Competence for Sustainable Development - Fundamental Module#	10
1	30-PHY-BIPSQ1	Deutschkurs A1.1 (German Course A1.1)	5
4	30-PHY-BIPSQ2	Deutschkurs A1.2 (German Course A1.2)	5
5	30-PHY-BIPSQ3	Deutschkurs A2 (German Course A2)	5
1 – 6		any module(s) from other study programs*	10

5 – 8		***Physics-Related Electives *****	***40***
5 – 8		*Introduction into Specialization*	*≤ 25*
5/7	12-PHY-BW3MO1	Introduction to Photonics I	5
5/6/7/8	12-PHY-BMWMO2	Introduction to Polymer Physics	5
5/7	12-PHY-BW3CS1	Introduction to Computer Simulations I	5
5/6/7/8	12-PHY-BMWEMB	Introduction to Biophysical Methods	5
4/6	12-PHY-BMWMED1	Introduction to Medical Physics	5
5/7	12-PHY-BW3HL1	Semiconductor Physics I	10
5/7	12-PHY-BW3HL2	Laboratory Work in Semiconductors I	5
5/6/7/8	12-PHY-BMWOFP1	Surface Physics, Nanostructures and Thin Films	5
5/7	12-PHY-BMWIOM2	Plasma Physics, Thin Film Deposition and Characterization	5
6/8	12-PHY-BMWIOM3	Microstructural Characterization	5
5/7	12-PHY-BMWQMAT	Quantum Matter	5
5/7	12-PHY-BW3QN1	Quantum Physics of Nanostructures	5
5/7	12-PHY-BMWQT1	Quantum Technology I	5
6/8	12-PHY-BMWQTPR	Quantum Technology – Lab Course	5
5/6/7	12-PHY-BMWQC1	Quantum Communication	5
6/7/8	12-PHY-BMWQS1	Quantum Sensing	5
5/7	12-PHY-BW3MQ1	Spin Resonance I	5
6/8	12-PHY-BW3SU1	Superconductivity I	5
5/6/7/8	12-PHY-BMWSUM	Fundamentals of Magnetism	5
5	12-PHY-BIOPL	Open Project Lab	5
6/8	12-PHY-BW3XAS1	Stellar Physics	5
6/8	12-PHY-BMWXAS2	Stellar Physics Laboratory	5
5/7	12-PHY-BMWXAS3	Extragalactic Astronomy and Cosmology	5
5/7	12-PHY-BMWXAS4	Extragalactic Astronomy Laboratory	5

5 – 8		*Deepening the Specialization*	*≥ 15*
6/8	12-PHY-MWPSUM2	Superconductivity II	5
7	12-PHY-MWPSUM3	Laboratory Superconductivity and Magnetism	5
6/7/8	12-PHY-MWPIOM6	Magnetism	5
6/8	12-PHY-MWPSEF1	X-ray Techniques	5
6/8	12-PHY-MWPHLP3	Semiconductor Physics II: Semiconductor Devices	5
6/8	12-PHY-MWPHLP5	Laboratory Work in Semiconductors II	5
7-8	12-PHY-MWPHLP6	Semiconductor Physics III: Semiconductor Optics (module runs over 2 semesters)	5
6/8	12-PHY-MWPAMR1	Magnetic Resonance and Imaging in Soft Matter	5
6/7/8	12-PHY-MWPMQ3	Nuclear Magnetic Resonance Laboratory	5
6/7/8	12-PHY-MWPMQ4	Electronic Spin Resonance Laboratory	5

7	12-PHY-MWPKP1	Nuclear Physics	5
8	12-PHY-MWPXT2	Particle Physics	5
6/8	12-PHY-MWPQT2	Quantum Technology 2	5
7	12-PHY-MWPQT3	Quantum Technology 3	5
6/8	12-PHY-MWPMON3	Active Matter Physics	5
6/7/8	12-PHY-MWPGFP	Physics of Nanoporous Materials	5
7	12-PHY-MWPEMSP	Single-Molecule Spectroscopy	5
7	12-PHY-MWPM1	Cellular Biophysics	5
6/8	12-PHY-MWPM3	Experimental Methods in Biophysics	5
7	12-PHY-MWPPOC1	Physics of Cancer I	5
6/8	12-PHY-MWPPOC2	Physics of Cancer II	5
6/7/8	12-PHY-MWPTKS1	Stochastic Processes in Physics, Biology and Earth Sciences	10
6/7/8	12-PHY-MWPTKS2	Non-linear Dynamics and Pattern Formation	10
6/7/8	12-PHY-MWPTKS3	Practical Course: Complex Systems	5
6/7/8	12-PHY-MWPTKM3	Theory of Soft and Bio Matter	10
6/7/8	12-PHY-MWPTKM4	Practical Course: Condensed Matter Theory	5
6/7/8	12-PHY-MWPQCM1	Practical Course: Quantum Theory of Condensed Matter	5
7	12-PHY-MWPQFG1	General Relativity	10
6/8	12-PHY-MWPQFG2	Cosmology	10
6/7/8	12-PHY-MWPQFG3	Quantum Field Theory on Curved Space Times	10
6/7/8	12-PHY-MWPQFG6	Practical Course: Quantum Field Theory and Gravity	5
6/7/8	12-PHY-MWPTET4	Relativistic Quantum Field Theory	10
6/7/8	12-PHY-MWPSTP1	Quantum Field Theory of Many-Particle Systems	10
7/8	12-PHY-MWPSTP2	Statistical Mechanics of Deep Learning	10
6/7/8	12-PHY-MWPTKM5	Practical Course: Quantum Statistical Physics	5
6/8	12-PHY-MWPMMP1	Black Holes	10
6/7/8	12-PHY-MWPXT1	Group Theory and Its Applications in Physics	10
		Optional: Non-completed modules of the Advanced Experimental or Advanced Theoretical Electives; one additional Advanced Seminar module	
8		***Final Thesis and Colloquium***	***15***
8	12-PHY-BS-IPSPHON	Bachelor's Thesis (contributes with double weighting to the final grade)	10
8	12-PHY-BICOL	Bachelor Thesis Colloquium	5
		Total	**240**

Only one of the two modules 12-SQM-64 and 12-PHY-BMWBNE1 can be completed.

* Up to 10 CP of any module(s) offered in other study programs can be chosen according to valid cooperation agreements. Further modules can be approved by the examination board upon request.

** Please note, that not all electives can be offered once a year. Check out the Course Catalogue for the list of modules being offered in the upcoming semester.

2 Module Descriptions

2.1 Experimental Physics

Experimental Physics 1 – Mechanics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	1st semester	every winter semester	**12-PHY-BIEP1** **8 CP**
Workload 240 h	Tutorial hours 90 h	Private study hours 150 h	
Responsibility			
Director of the Peter Debye Institute for Soft Matter Physics / Director of the Felix Bloch Institute for Solid State Physics			
Teaching units (SWS / tutorial hours / private study hours)			
- Lecture “Experimental Physics 1 - Mechanics” (4 SWS / 60 h / 90 h) - Exercise “Experimental Physics 1 - Mechanics” (2 SWS / 30 h / 60 h)			
Participation requirements			
None			
Examinations (duration; weighting) and pre-examination requirements			
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

Students grasp the basic terms, phenomena and concepts of mechanics. After active participation in the module they are able to analyze and solve problems from these areas independently. They can apply the acquired knowledge to typical experiments and transfer it to new problems. They are able to describe and discuss problems and solutions of tasks in mechanics using appropriate scientific terms.

Content

- kinematics and dynamics of the mass point, Newton’s laws, force
- Galilei transformation, accelerated reference systems, inertial forces
- special theory of relativity
- conservation laws: momentum, energy, angular momentum
- gravity and planetary motion
- systems of centres of mass, laws of impact
- statics and dynamics of rigid bodies
- oscillations, Fourier analysis
- waves, acoustics
- mechanics of deformable bodies
- mechanics of static and moving fluids
- frictional forces
- classical chaos

References

- M. Alonso / E. J. Finn: Physics, Addison-Wesley Longman
- D. Halliday / R. Resnick / J. Walker: Fundamentals of Physics, Wiley-VCH
- A. P. French "Special Relativity", The M.I.T. Introductory Physics Series

Experimental Physics 2 – Thermo- and Electrodynamics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	2^{nd} semester	every summer semester	**12-PHY-BIEP2** **8 CP**
Workload: 240 h	Tutorial hours: 90 h	Private study hours: 150 h	

Responsibility
Director of the Peter Debye Institute for Soft Matter Physics / Director of the Felix Bloch Institute for Solid State Physics

Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Experimental Physics 2 - Thermo- and Electrodynamics” (4 SWS / 60 h / 90 h) - Exercise “Experimental Physics 2 - Thermo- and Electrodynamics” (2 SWS / 30 h / 60 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students grasp the basic terms, phenomena and concepts of thermo- and electrodynamics. After active participation in the module they are able to analyze and solve problems from these areas independently. They can apply the acquired knowledge to typical experiments and transfer it to new problems. They are able to describe and discuss problems and solutions of tasks in thermo- and electrodynamics using appropriate scientific terms.

Content

Thermodynamics
- diffusion, Brownian motion
- ideal gas, kinetic gas theory, Maxwell-Boltzmann distribution
- main theorems of thermodynamics, temperature, heat capacity
- closed and open systems, reversibility
- entropy, cyclic processes, thermodynamic machines, efficiency
- fundamentals of statistical physics, statistical definition of entropy, Boltzmann Distribution
- real gas and phase transitions
- thermal conductivity

Electro- and magnetostatics
- static electric fields: Coulomb's law, electric charge, electric field, potential and voltage, electric dipole, capacitor, dielectric displacement, Gaussian law
- static magnetic fields: current density, magnetic field, Biot-Savartes Law, forces on conductors, magnetic dipole, Ampere's Law
- moving charges: Charge carriers in electric and magnetic fields, Lorentz force
- electromagnetic properties of matter: metals, semiconductors, dielectrics

References

- M. Alonso / E. J. Finn: Physics, Addison-Wesley Longman
- D. Halliday / R. Resnick / J. Walker: Fundamentals of Physics, Wiley-VCH

Experimental Physics 3 – Electromagnetic Waves and Foundations of Quantum Physics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	3rd semester	every winter semester	**12-PHY-BIEP3** **8 CP**
Workload	Tutorial hours	Private study hours	
240 h	90 h	150 h	

Responsibility
Director of the Peter Debye Institute for Soft Matter Physics / Director of the Felix Bloch Institute for Solid State Physics
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Experimental Physics 3 - Electromagnetic Waves and Foundations of Quantum Physics" (4 SWS / 60 h / 90 h) - Exercise "Experimental Physics 3 - Electromagnetic Waves and Foundations of Quantum Physics" (2 SWS / 30 h / 60 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students grasp the basic terms, phenomena and concepts of optics and quantum physics. After active participation in the module they are able to analyze and solve problems from these areas independently. They can apply the acquired knowledge to typical experiments and transfer it to new problems. They are able to describe and discuss problems and solutions of tasks in optics and quantum physics using appropriate scientific terms.

Content

Electromagnetic waves

- electromagnetic waves: wave equation, electromagnetic spectrum, plane and spherical waves, energy transport and Poynting vector, polarization, reflection and transmission, Fresnel formulas, Hertzian dipole
- wave optics: Huygen's principle, diffraction, interference, coherence, interferometer, single and double slit, diffraction grating,

Geometrical optics:

- reflection, refraction, mirrors, lenses, prisms, optical instruments, dispersion, imaging errors

Fundamentals of quantum physics

- particle properties of light: photoelectric effect, blackbody radiation, photon gas, Planck's law of radiation
- structure of matter: Thomson's atomic model, Rutherford scattering, Rutherford's and Bohr's atomic models
- matter waves: Heisenberg principle of uncertainty, wave function, probability interpretation
- Schrödinger equation, quantum states, potential well, harmonic oscillator, tunnel effect, correspondence principle

References

- M. Alonso / E. J. Finn: Physics, Addison-Wesley Longman
- D. Halliday / R. Resnick / J. Walker: Fundamentals of Physics, Wiley-VCH

Experimental Physics 4 – Atomic and Molecular Physics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	4th semester	every summer semester	**12-PHY-BIEP4 7 CP**
Workload: 210 h	Tutorial hours: 90 h	Private study hours: 120 h	
Responsibility: Director of the Peter Debye Institute for Soft Matter Physics / Director of the Felix Bloch Institute for Solid State Physics			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Experimental Physics 4 - Atomic and Molecular Physics" (4 SWS / 60 h / 80 h) - Exercise "Experimental Physics 4 - Atomic and Molecular Physics" (2 SWS / 30 h / 40 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

Students grasp the basic terms, phenomena and concepts of atomic and molecular physics. After active participation in the module they are able to analyze and solve problems from these areas independently. They can apply the acquired knowledge to typical experiments and transfer it to new problems. They are able to describe and discuss problems and solutions of tasks in atomic and molecular physics using appropriate scientific terms.

Content

Atomic physics:
- hydrogen atom: Schrödinger equation, orbitals, energy and angular momentum quantization
- spin and star-gerlach experiment, spin-orbit coupling, relativistic effects
- atoms with several electrons: Pauli principle, Hund's rules, systematics of atomic structure, periodic table
- atoms in external fields, spectroscopy, optical transitions, selection rules, laser
- fundamentals of quantum statistics: Fermi-Dirac and Bose-Einstein statistics, Bose- Einstein condensation

Molecular physics:
- H_2 molecule, molecular orbitals (LCAO)
- chemical bonds, hybridization, quantum chemistry
- rotation and vibration states of molecules, degrees of freedom
- molecular spectroscopy (IR-FTIR, Raman, Brillouin, NMR, fluorescence)

References

- M. Alonso / E. J. Finn: Physics, Addison-Wesley Longman
- C.J. Foot: Atomic Physics, Oxford Master Series
- H. Haken / H. C. Wolf: Molecular Physics and Elements of Quantum Chemistry, Springer
- A. P. Sutton: Electronic Structures of Materials, Oxford University Press
- C. Kittel / H. Krömer: Thermal Physics, W. H. Freeman
- H. B. Callen: Thermodynamics, Wiley
- T. L. Hill: An Introduction to statistical mechanics, Addison-Wesley

Experimental Physics 5 – Soft Matter

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	5th semester	every winter semester	**12-PHY-BIEP5** **7 CP**
Workload: 210 h	Tutorial hours: 90 h	Private study hours: 120 h	

Responsibility
Director of the Peter Debye Institute for Soft Matter Physics

Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Experimental Physics 5 – Soft Matter” (4 SWS / 60 h / 80 h)
- Exercise “Experimental Physics 5 – Soft Matter” (2 SWS / 30 h / 40 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1)

Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.

Objectives

Students grasp the basic terms, phenomena and concepts of soft matter physics. After active participation in the module, they are able:
- to analyze and independently solve tasks from soft matter physics.
- to apply the acquired knowledge to typical experiments and transfer it to new problems.
- to discuss scientifically with terms of soft matter physics and to present and justify their solutions to soft matter physics tasks.

The students know experimental as well as theoretical methods and concepts to describe and investigate such systems. With the acquired theoretical knowledge, the students can independently address tasks/application examples in the field of soft matter physics and discuss them in the accompanying exercise.

Content

Soft matter physics is a subfield of condensed matter and includes a variety of physical states whose equilibrium and dynamics are largely determined by thermal fluctuations. Students will acquire an overview of the structure and description of various soft matter material systems, such as:
- liquids, colloids, liquid crystals, polymers, biological matter, molecules

and their special properties, e.g.
- phase transitions, order phenomena, entropic effects (elasticity, segregation), fluctuation forces, viscoelasticity, behavior and dynamics of overdamped systems

Students learn important methods for investigating soft matter. Furthermore, they deepen their knowledge in
- statistical physics, molecular interaction forces, hydrodynamics, transport processes, diffusion and Brownian motion

References

- Jacob N. Israelachvili: Intermolecular and Surface Forces: With Applications to Colloidal and Biological Systems (Academic Press)
- M. Doi und S.F. Edwards: The Theory of Polymer Dynamics (Oxford Academic Press)
- P.G. de Gennes and J. Prost: The Physics of Liquid Crystals (Oxford Academic Press)
- Rob Pillips, Jane Kondev, Julie Theriot: Physical Biology of the Cell (Garland Science)
- Jonathan Howard: Mechanics of Motor proteins and the Cytoskeleton (Sinauer Associates)

Experimental Physics 6 – Solid State Physics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	6^{th} semester	every summer semester	**12-PHY-BIPEP5** **7 CP**
Workload: 210 h	Tutorial hours: 90 h	Private study hours: 120 h	

Responsibility
Director of the Felix Bloch Institute for Solid State Physics

Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Experimental Physics 6 - Solid State Physics” (4 SWS / 60 h / 80 h) - Exercise “Experimental Physics 6 - Solid State Physics” (2 SWS / 30 h / 40 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students grasp the basic terms, phenomena and concepts of solid state physics. After active participation in the module they are able to analyze and solve problems from these areas independently. They can apply the acquired knowledge to typical experiments and transfer it to new problems. They are able to describe and discuss problems and solutions of tasks in solid state physics using appropriate scientific terms.

Content

- Drude model: free electron gas, Hall effect, frequency dependent conductivity, optical properties
- crystals: chemical bonds in solids, crystal structures, Bravais lattice and reciprocal lattice, diffraction methods
- lattice vibrations: classical and quantum theory of the harmonic lattice, phonons, density of states, thermal properties, elastic constants, spectroscopic methods
- conduction electrons in solids: Bloch's theorem, quasi-free electron model, band model, tight-binding model, electrical and thermal properties, magnetotransport phenomena, fundamentals of semiconductor physics and superconductivity

References

- C. Kittel "Introduction to Solid State Physics" Wiley
- J. Sólyom "Fundamentals of the Physics of Solids (Vol. 1 and 2)" Springer
- G. Grosso and G. P. Parravicini "Solid State Physics" Academic Press
- Ashcroft, Mermin "Solid State Physics" Holt-Saunders Int. Ed.
- Ibach, Lüth "Solid-State Physics" Springer
- Duan, Guojun "Introduction to Condensed Matter Physics Vol. 1" World Scientific

2.1.1 *Electives in Advanced Experimental Physics*

Advanced Soft Matter and Biological Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th} / 7^{th} semester	irregular cycle	**12-PHY-MWPASM 10 CP**
Workload: 300 h	Tutorial hours: 105 h	Private study hours: 195 h	

Responsibility
Head of the Soft Matter Physics Division

Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Advanced Soft Matter and Biological Physics" (4 SWS / 60 h / 120 h) - Seminar "Advanced Soft Matter and Biological Physics" (2 SWS / 30 h / 45 h) - Exercise "Advanced Soft Matter and Biological Physics" (1 SWS / 15 h / 30 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1) *Pre-examination requirements: Seminar presentation with discussion (30 min.).*

Objectives

Students will grasp the basic terms, phenomena and concepts of solid state physics. After active participation in the module, they will be able to analyze and independently solve problems from these areas. Students will be able to apply the knowledge they have gained to typical experiments and to new problems. They will be able to perform scientific discussions with terms of solid state physics and to present, and argumentatively justify, their solutions to problems in this field.

Content

The course covers topical, relevant subjects in the fields of soft matter and biological physics.
The basic topics for this are:

- Polymer networks (interwoven, cross-linked, active elements)
- Statics and dynamics of networks/bundles
- Liquid crystals, lipid membranes, viscoelasticity
- Non-affine & non-linear behavior of soft matter
- Time-temperature superposition
- Non-equilibrium segregation, non-equilibrium fluctuations
- Equilibrium self-assembly vs. non-equilibrium self-organization
- Plasticity, active behavior, ruptures, non-linear properties
- Jamming transitions & glassy behavior
- Non-equilibrium dynamics and entropy of living systems

References

- M. Doi, S.F. Edwards: The Theory of Polymer Dynamics (Oxford Science Publication)
- P.G. de Gennes and J. Prost: The Physics of Liquid Crystals (Oxford Academic Press)
- Florian Huber, Jörg Schnauß, Susanne Rönicke, Philipp Rauch, Karla Müller, Claus Fütterer, Josef Käs: Emergent complexity of the cytoskeleton: from single filaments to tissue, Advances in Physics, Volume 62, Issue 1 (2013)
- Bruce Alberts: Molecular Biology of the Cell (Taylor & Francis Ltd.)

Advanced Solid State Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th} / 7^{th} semester	irregular cycle	**12-PHY-MWPE1** **10 CP**
Workload 300 h	Tutorial hours 105 h	Private study hours 195 h	
Responsibility Director of the Felix Bloch Institute for Solid State Physics			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Advanced Solid State Physics” (4 SWS / 60 h / 60 h) - Seminar “Advanced Solid State Physics” (2 SWS / 30 h / 60 h) - Exercise “Advanced Solid State Physics” (1 SWS / 15 h / 75 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

After active participation in the module, the students will be able to understand complex phenomena of solid state physics and how they can be caused by microscopic, quantum mechanical and collective mechanisms. Students will be able to access advanced methods and experiments in the field of solid state physics. They will learn typical computational methods and apply them to advanced problems in the field of advanced solid state physics.

Content

The course covers spezcific fields of solid state physics, which are also the subject of current research at the Faculty, such as:

- Magnetism
- Superconductivity
- Correlated systems
- Systems with reduced dimensionality
- Surface physics
- Structural analysis of complex solids
- Spectroscopy of quantum solids
- Advanced areas of semiconductor physics

References

- Ch. Kittel, Einführung in die Festkörperphysik/Introduction to Solid State Physics (Oldenbourg/Wiley)
- N.W. Ashcroft, D.N. Mermin, Festkörperphysik/Solid State Physic (Oldenbourg/Holt/Cengage Learning)
- P. Philips, Advanced Solid State Physics (Cambridge University Press)

2.2 Theoretical Physics

Theoretical Physics 1 – Classical Mechanics 1

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	1st semester	every winter semester	**12-PHY-BIPTP1 8 CP**
Workload: 240 h	Tutorial hours: 90 h	Private study hours: 150 h	
Responsibility: Director of the Institute for Theoretical Physics			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Theoretical Physics 1 - Classical Mechanics 1” (4 SWS / 60 h / 100 h) - Exercise “Theoretical Physics 1 - Classical Mechanics 1” (2 SWS / 30 h / 50 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

The students
- learn basic principles of mechanics and can apply them to relevant problems;
- master basic calculation methods of classical mechanics;

Content

- Newton’s axioms, laws of conservation
- differentiating and integrating functions of one variable, calculating with complex numbers, solving ordinary differential equations
- non-inertial systems
- calculating with matrices and determinants, coordinate systems and rotations
- Kepler problem, mechanics of mass points and rigid bodies, small oscillations
- linear systems of equations, eigenvalue problems

References

- D. Kleppner and R.J. Kolenkov, "An Introduction to Mechanics", Cambridge University Press
- David Morin: Classical Mechanics, Cambridge
- John R. Taylor: Classical Mechanics, Univ. Sc. Books

Theoretical Physics 2 – Electrodynamics 1

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	2nd semester	every summer semester	**12-PHY-BIPTP2 8 CP**
Workload: 240 h	Tutorial hours: 90 h	Private study hours: 150 h	

Responsibility	Director of the Institute for Theoretical Physics
Teaching units (SWS / tutorial hours / private study hours)	- Lecture “Theoretical Physics 2 - Electrodynamics 1” (4 SWS / 60 h / 100 h) - Exercise “Theoretical Physics 2 - Electrodynamics 1” (2 SWS / 30 h / 50 h)
Participation requirements	none
Examinations (duration; weighting) and pre-examination requirements	Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

The students
- know basic concepts of classical electrodynamics and can apply them to relevant issues;
- master basic calculation methods of classical electrodynamics;

Content

- Maxwell's equations, laws of conservation
- introduction into vector analysis in R^3: div, red, grad, area and volume integrals
- electrostatics and magnetostatics in vacuum and media, law of induction and quasi-stationary currents
- elementary solution methods for partial differential equations

References

- D.J. Griffiths "Introduction to Electrodynamics" Pearson Education 2008
- D. Jackson "Classical Electroynamics" John Wiley & Sons 1998

Theoretical Physics 3 – Classical Mechanics 2 and Electrodynamics 2

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	3rd semester	every winter semester	**12-PHY-BIPTP3** **8 CP**
Workload 240 h	Tutorial hours 90 h	Private study hours 150 h	
Responsibility Director of the Institute for Theoretical Physics			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Theoretical Physics 2 - Classical Mechanics 2 and Electrodynamics 2” (4 SWS / 60 h / 100 h) - Exercise “Theoretical Physics 2 - Classical Mechanics 2 and Electrodynamics 2” (2 SWS / 30 h / 50 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

The students
- know concepts of classical mechanics and electrodynamics and can apply them to relevant problems;
- gain an insight into the systematizing way of thinking and formal description of physical contents;
- are proficient in calculation methods of classical mechanics and electrodynamics;

Content

- constraints and D'Alembert's principle
- Lagrange equations of 1st and 2nd kind, Noether theorem, Hamiltonian principle
- Hamiltonian equations, canonic transformations, Hamilton-Jacobi equation, integrable systems
- special theory of relativity
- method of Green's functions for partial differential equations
- electromagnetic waves in vacuum and media, field of moving charges, radiation

References

- David Morin: Classical Mechanics, Cambridge
- John R. Taylor: Classical Mechanics, Univ. Sc. Books
- Jorge V. Jose: Classical Dynamics (A Contemporary Approach), Cambridge
- D.J. Griffiths, "Introduction to Electrodynamics", Pearson
- J.D. Jackson "Classical Electroynamics", Wiley

Theoretical Physics 4 – Quantum Mechanics

<table>
<tr><td>Module type
compulsory</td><td>Recommended for
4th semester</td><td>Module availability
every summer semester</td><td rowspan="2">Module number and ECTS
12-PHY-BIPTP4
8 CP</td></tr>
<tr><td>Workload
240 h</td><td>Tutorial hours
90 h</td><td>Private study hours
150 h</td></tr>
<tr><td colspan="4">Responsibility
Director of the Institute for Theoretical Physics</td></tr>
<tr><td colspan="4">Teaching units (SWS / tutorial hours / private study hours)
- Lecture “ Theoretical Physics 4 - Quantum Mechanics” (4 SWS / 60 h / 100 h)
- Exercise “ Theoretical Physics 4 - Quantum Mechanics” (2 SWS / 30 h / 50 h)</td></tr>
<tr><td colspan="4">Participation requirements
None</td></tr>
<tr><td colspan="4">Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1)
Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.</td></tr>
</table>

Objectives

The students
- cover the basic concepts for the description of physical systems in quantum mechanics;
- know the concept and the formal apparatus of quantum mechanics as well as typical fields of application;
- can use it to address simple problems;

Content

- elementary phenomena, Schrödinger’s equation, superposition principle, states in Hilbert space
- observables, operators in Hilbert space, eigenvalue, spectrum, scattering, time evolution, uncertainty relation
- one-dimensional problems
- theory of angular momentum, spin
- central potentials, introduction into scattering theory and perturbation theory

References

- D.J. Griffiths "Introduction to Quantum Mechanics", Pearson Education 2005
- F. Schwabl "Quantum mechanics" Springer 2008

Theoretical Physics 5 – Statistical Physics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	5th semester	every winter semester	**12-PHY-BIPTP5** **8 CP**
Workload 240 h	Tutorial hours 90 h	Private study hours 150 h	

Responsibility
Director of the Institute for Theoretical Physics
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Theoretical Physics 5 - Statistical Physics" (4 SWS / 60 h / 100 h) - Exercise "Theoretical Physics 5 - Statistical Physics" (2 SWS / 30 h / 50 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

The students
- can illustrate and explain the basic concepts of thermodynamics and statistical physics of equilibrium orally and written form;
- can use them to investigate and predict the behaviour of simple classical and quantum mechanical many-body systems in thermodynamic equilibrium;
- can examine and solve simple model problems independently and discuss their approach;

Content

- terms and principles of thermodynamics, thermodynamic potentials, equilibrium conditions, ideal and real gases, phase transitions
- basic concepts of kinetic gas theory, statistical mechanics of equilibrium, classical and quantum systems, approximation methods
- introduction into quantum statistics

References

- C. Kittel and H. Kroemer, "Thermal Physics", 2nd ed., Freeman
- M. Kardar, "Statistical Mechanics of Particles", Cambridge University Press, 2007

2.2.1 *Electives in Advanced Theoretical Physics*

Advanced Quantum Mechanics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPT1 10 CP**
Workload	Tutorial hours	Private study hours	
300 h	90 h	210 h	

Responsibility
Head of the Department of Quantum Field Theory and Gravitation
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Advanced Quantum Mechanics” (4 SWS / 60 h / 80 h) - Exercise “Advanced Quantum Mechanics” (2 SWS / 30 h / 130 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Regularly handed out exercises with tasks related to the module content. Points are awarded for solutions. Prerequisite for admission is the achievement of 50% of the possible points of the entire semester.*

Objectives

After active participation in the module, students will be able to:

- Present and explain the basic terms, concepts, methods and results of advanced quantum mechanics both in oral and written form
- Apply them to study and predict the behavior of quantum mechanical systems
- Work independently on simple model problems, solve them, and justify them
- Apply the acquired knowledge to new problems
- Use the literature to independentlz extend their knowledge in the field

Content

- State space
- Basic concepts of quantum information
- Symmetry and invariance
- Identical particles
- Scattering theory
- Approximation methods for bound states (time-dependent and time-independent perturbation theory, variational methods)
- Relativistic quantum mechanics

References

- A. Galindo, P. Pascual: Quantum Mechanics 1 & 2, Springer TMP, 1991
- A. Peres: Quantum Theory: Concepts and Methods, Kluwer 1998
- F. Schwabl: Advanced Quantum Mechanics, Springer, 2005

Advanced Statistical Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7^{th} / 8^{th} semester	every summer semester	**12-PHY-MWPT2** **10 CP**
Workload 300 h	Tutorial hours 90 h	Private study hours 210 h	
Responsibility Head of the Department of Theory of Condensed Matter, Head of the Department of Elementary Particle Theory			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Advanced Statistical Physics” (4 SWS / 60 h / 80 h) - Exercise “Advanced Statistical Physics” (2 SWS / 30 h / 130 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (120 min; ×1) *Pre-examination requirements: Regularly handed out exercises with tasks related to the module content. Points are awarded for solutions. Prerequisite for admission is the achievement of 50% of the possible points of the entire semester.*			

Objectives

After active participation in the module, students will be able to:
- Present and explain the basic terms, concepts, methods and results of advanced statistical physics both in oral and written form
- Apply them to study and predict the behavior of systems with many degrees of freedom
- Work independently on simple model problems, solve them and justify them
- Apply the acquired knowledge to new problems
- Use the literature to independentlz extend their knowledge in the field

Content

- Deepening of concepts and relevant examples of equilibrium-statistical mechanics
- Critical phenomena and renormalization group
- Thermodynamics and non-equilibrium statistical mechanics
- Introduction to stochastic processes and algorithms

References

- M. Kardar, "Statistical Mechanics of Particles", Cambridge University Press, 2007
- M. Kardar, "Statistical Mechanics of Fields", Cambridge University Press, 2007

2.3 Laboratory Courses

Introduction to Computer-based Physical Modelling

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	2^{nd} semester	every summer semester	**12-PHY-BWMS 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department “Molecular Nanophotonics”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Introduction to Computer-based Physical Modelling” (2 SWS / 30 h / 45 h) - Exercise “Introduction to Computer-based Physical Modelling” (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Portfolio (×1)			

Objectives

The aim of this module is to become familiar with the programming language Python and to apply it to problems in physics. After active participation, the students are able to analyse and graphically display experimental data in Python, to simulate physical and non-physical problems, to solve them numerically and to display them graphically. A short introduction to machine learning is intended to sensitise the students to new procedures.

Content

- basics of the programming language Python
- documentation in Jupyter Notebooks
- data exchange with files
- graphical representation of scientific data
- fitting theoretical models to experimental data
- simple numerical solutions of differential equations and systems of differential equations
- the application of numerical methods to physical processes from statistical physics, mechanics, electrostatics and electrodynamics, optics and quantum mechanics
- brief introduction to machine learning methods

References

- A. Malthe-Sørenssen: Elementary mechanics using Python, Springer, 2015
- J. M. Kinder, P. A. Nelson: A student’s guide to Python for physical modeling, Princeton University Press, 2018
- H. P. Langtangen: A primer on scientific programming with Python, Springer, 2016
- R. Maeder: Programming in Mathematica, 3. Auflage, Addison-Wesley, 1997
- R. Gaylord, S. N. Kamin, P. R. Wellin: Introduction to programming with Mathematica, TELOS, 1993
- R. Maeder: Informatik für Mathematiker und Naturwissenschaftler, Addison-Wesley, 1993
- A. Géron: Hands-on machine learning with Scikit-Learn, Keras, and Tensor Flow, O’Reilly, 2020

General Physics Laboratory 1

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	3rd semester	every winter semester	**12-PHY-BIGP1** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the General Physics Laboratory			
Teaching units (SWS / tutorial hours / private study hours): - Laboratory "General Physics Laboratory 1" (4 SWS / 60 h / 90 h)			
Participation requirements: Completion of module „Experimental Physics 1 – Mechanics" (12-PHY-BIEP1); Participation in the occupational health and safety training			
Examinations (duration; weighting) and pre-examination requirements: Lab reports (10 opening tests, 10 written reports (preparation time 1 week); ×1)			

Objectives

The students
- acquire a deeper understanding of physical relations;
- know basic experimental techniques, important rules of report preparation and simple procedures of data analysis.

Content

In the basic physics laboratory 1 two experiments for data acquisition and data analysis as well as eight experiments from the fields of mechanics, thermodynamics and electricity are to be carried out.

The practical course requires intensive preparation for each experiment so that the tasks can be executed independently.

References

- Y. Kraftmakher, Experiments and Demonstrations in Physics, World Scientific
- J.R. Taylor, An Introduction to Error Analysis

General Physics Laboratory 2

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	4th semester	every summer semester	**12-PHY-BIGP2** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the General Physics Laboratory			
Teaching units (SWS / tutorial hours / private study hours): - Laboratory “General Physics Laboratory 2” (4 SWS / 60 h / 90 h)			
Participation requirements: Completion of module „Experimental Physics 2 – Thermo- and Electrodynamics“ (12-PHY-BIEP2); Participation in the occupational health and safety training			
Examinations (duration; weighting) and pre-examination requirements: Lab reports (10 opening tests, 10 written reports (preparation time 1 week); ×1)			

Objectives

The students
- acquire a deeper understanding of physical relations;
- know basic experimental techniques, important rules of report preparation and simple procedures of data analysis;
- have developed the ability to critically evaluate the experimental results and set-ups;
- can present their results;
- have learned to work in a team and to communicate scientifically with each other.

Content

In the basic physics laboratory 2 ten experiments from the fields of electricity, optics and atomic physics are to be carried out.

The practical course requires intensive preparation for each experiment so that the tasks can be executed independently.

References

- Y. Kraftmakher, Experiments and Demonstrations in Physics, World Scientific
- J.R. Taylor, An Introduction to Error Analysis

Advanced Departmental Lab

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	6^{th} semester	every summer semester	**12-PHY-BIADL 8 CP**
Workload 240 h	Tutorial hours 90 h	Private study hours 150 h	

Responsibility
Head of the Advanced Physics Laboratory
Teaching units (SWS / tutorial hours / private study hours)
- Laboratory “Advanced Physics Laboratory” (6 SWS / 60 h / 90 h)
Participation requirements
Participation in the modules 12-PHY-BIEP1 to -BIEP4 and 12-PHY-BIPTP1 to -BIPTP4
Examinations (duration; weighting) and pre-examination requirements
Lab reports (preparation time 2 weeks; ×1)

Objectives

The students
- expand their knowledge of basic experimental procedures in modern physics and become familiar with sophisticated experimental techniques in the scientific environment of the faculty;
- gain their own experimental insights into spectroscopic standard methods and their theoretical models for the interpretation of results and can apply them independently;
- learn to adopt themselves with challenging scientific tasks, to implement them creatively, and to present and defend the physical principles and the obtained results.

Content

Students select three departments of the Physics Institutes and perform an experimental or practical course of current research in each department. Each experiment/practical course is completed by a written lab report.

Alternatively, students may perform Advanced Laboratory (FP) experiments. In this case, two experiments of the FP replace one departmental experiment/practical course. The experiments can be chosen from the following experimental complexes:
- nuclear and electron spin resonance (NMR, EPR)
- optical pumping, laser spectroscopy
- molecular and lattice vibrations (IR1+2, Raman, FTIR)
- semiconductors (photoluminescence, Hall effect)
- electronic states (Franck-Hertz experiment, colour centres, Zeeman effect)
- structural analysis with X-ray scattering (XRD1+2)
- radioactivity (gamma, alpha decay)
- scanning probe microscopy (AFM, STM), mass spectrometry

Notes on the examination: Portfolio Each of the departmental labs and, if option for replacement is used, each of the advanced lab experiments has to be passed.

References

Recommendations for references and literature will follow in the course.

2.4 Mathematics

Mathematics 1 – Linear Algebra and Calculus of Functions of One Variable

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	1^{st} semester	every winter semester	**10-PHY-BIMA1** **9 CP**
Workload: 270 h	Tutorial hours: 90 h	Private study hours: 180 h	

Responsibility
Director of the Institute for Mathematics

Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Linear Algebra and Calculus of Functions of One Variable” (4 SWS / 60 h / 110 h) - Exercise “Linear Algebra and Calculus of Functions of One Variable” (2 SWS / 30 h / 70 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Written exam (120 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students learn the basics of linear algebra and calculus. They are able to present and explain the acquired knowledge on concepts and terms orally and in writing and can apply it to typical problems in order to solve them independently and to justify their approach.

Content

- basic concepts of linear algebra, groups, arithmetic with matrices
- convergence of sequences and series
- continuous functions
- differential calculus for functions of a variable
- integral calculation for functions of a variable, Riemann integral

References

- Serge Lang: Linear Algebra, Springer
- Serge Lang: A First Course in Calculus, Springer
- Kenneth A. Ross: Elementary Analysis, Springer
- Stephen Abbott: Understanding Calculus, Springer

Mathematics 2 – Calculus of Functions of More Than One Variable

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	2^{nd} semester	every summer semester	**10-PHY-BIMA2 9 CP**
Workload: 270 h	Tutorial hours: 90 h	Private study hours: 180 h	
Responsibility: Director of the Institute for Mathematics			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Calculus of Functions of More Than One Variable" (4 SWS / 60 h / 110 h) - Exercise "Calculus of Functions of More Than One Variable" (2 SWS / 30 h / 70 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Written exam (120 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

Students acquire a basic understanding in the calculus of functions of more than one variable. They are able to present and explain the acquired knowledge orally and in writing and are able to apply it to typical problems in order to solve them independently and to justify their actions.

Content

- functional sequences: even convergence, power series
- differential calculus for functions of more than one variable: derivation of functions f: R^n → R^m, chain rule, resolution theorems, Taylor's theorem, extrema, parameter-dependent integrals
- introduction to ordinary differential equations and systems

References

- Serge Lang: Calculus of Several Variables, Springer
- Vladimir I. Arnol'd: Ordinary Differential Equations, Springer

Mathematics 3 – Vector Calculus and Partial Differential Equations

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	3rd semester	every winter semester	**10-PHY-BIMA3** **9 CP**
Workload 270 h	Tutorial hours 90 h	Private study hours 180 h	

Responsibility
Director of the Institute for Mathematics

Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Vector Calculus and Partial Differential Equations" (4 SWS / 60 h / 110 h) - Exercise "Vector Calculus and Partial Differential Equations" (2 SWS / 30 h / 70 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Written exam (120 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students master the basics of vector analysis and know methods for solving partial differential equations. They are able to apply the acquired knowledge to typical problems, to solve them independently and to justify their approach.

Content

- vector analysis (rotation, divergence, gradient)
- curve integrals in R^n: rectifiable curves, curve integrals, path independence, potential fields
- area integrals and surface integrals: area integrals in R^n, variable transformation, surfaces, surface integrals, sets of Gauss and Stokes in R^3
- overview of the most important partial differential equations in physics, examples of solution methods

References

- Walter Rudin: Principles of Mathematical Analysis, McGraw-Hill
- Jon Pierre Fortney: A Visual Introduction to Differential Forms and Calculus on Manifolds, Springer
- Vladimir I. Arnol'd: Lectures on Partial Differential Equations, Springer

Order of Magnitude Physics

Module type	Recommended for	Module availability	Module number and ECTS
compulsory	4^{th} semester	every summer semester	**12-PHY-BIOMP** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department “Complex Systems”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Order of Magnitude Physics” (2 SWS / 30 h / 45 h) - Exercise “Order of Magnitude Physics” (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Term paper (preparation time 6 weeks; ×1)			

Objectives

Students acquire knowledge of basic physical techniques for analyzing measurement data and theoretical models. They are enabled to investigate the plausibility of physical laws on the basis of dimensional considerations, to determine relevant dimensionless control parameters, to formulate scientific hypotheses and to test them on the basis of measurement data.
The methods are used to infer physical laws in different fields of application, to determine and implement automated data evaluation, and to identify false working hypotheses when interpreting data.

Content

- dimensional analysis and Buckingham-Pi theorem
- graphical analysis of measurement data and data collapse
- automated data analysis using Python and Sage
- applications in fluid dynamics and the theory of complex systems

References

- D. Morin: "Introduction to Classical Mechanics" (Cambridge UP), Kapitel 1
- S. Mahajan: "Street Fighting Mathematics" (MIT Press)
- Clifford Swartz: "Back-of-the-Envelope Physics" (John Hopkins UP)
- J Harte: "Consider a Spherical Cow" (Univ. Sc. Books)
- A.C. Fowler: "Mathematical Models in the Applied Sciences" (Cambridge UP)
- J.P. Sethna: "Entropy, Order Parameters, and Complexity" (Oxford UP)

2.5 Advanced Seminars (Electives)

Specialized Topics of Solid State Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7/8 th semester	at least once a year	**12-PHY-MWPSKM 5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 120 h	
Responsibility Director of the Felix Bloch Institute for Solid State Physics			
Teaching units (SWS / tutorial hours / private study hours) Seminar “Specialized Topics of Solid State Physics” (2 SWS / 30 h / 120 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Project work (written report with preparation time 3 weeks, oral presentation of 45 min; ×1)			

Objectives

After active participation in the module, students are able to access and critically analyze literature sources on advanced topics in solid state physics. In addition, students will be able to familiarize themselves with a current research topic and present it in a comprehensible written and oral form. In this way, students deepen their skills in research and presentation techniques, in the preparation of scientific documents and in the structured presentation of complex scientific contexts.

Content

The seminar deals with a specific current research area in solid state physics. Topics from this research area are presented by the students in oral presentations supported by media and discussed in detail. Subsequently, the topics are presented in a written paper, in which the results of the discussion are explicitly addressed.

References

- R. Geroch: "Suggestions for giving talks"

Further recommendations for references and literature will follow in the course.

Specialized Topics of Soft Matter Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	$7^{th}/8^{th}$ semester	at least once a year	**12-PHY-MWPSWM 5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 120 h	
Responsibility: Director of the Peter Debye Institute for Soft Matter Physics			
Teaching units (SWS / tutorial hours / private study hours): Seminar “Specialized Topics of Soft Matter Physics” (2 SWS / 30 h / 120 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Project work (written report with preparation time 3 weeks, oral presentation of 45 min; ×1)			

Objectives

After active participation in the module, students are able to access and critically analyze literature sources on advanced topics in soft matter physics. In addition, students will be able to familiarize themselves with a current research topic and present it in a comprehensible written and oral form. In this way, students deepen their skills in research and presentation techniques, in the preparation of scientific documents and in the structured presentation of complex scientific contexts.

Content

The seminar deals with a specific current research area in solid state physics. Topics from this research area are presented by the students in oral presentations supported by media and discussed in detail. Subsequently, the topics are presented in a written paper, in which the results of the discussion are explicitly addressed.

References

- R. Geroch: "Suggestions for giving talks"

Further recommendations for references and literature will follow in the course.

Specialized Topics of Theoretical and Mathematical Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th/8th semester	at least once a year	**12-PHY-MWPSMP 5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 120 h	
Responsibility Director of the Institute for Theoretical Physics			
Teaching units (SWS / tutorial hours / private study hours) Seminar “Specialized Topics of Theoretical and Mathematical Physics” (2 SWS / 30 h / 120 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Project work (written report with preparation time 3 weeks, oral presentation of 45 min; ×1)			

Objectives

After active participation in the module, students are able to access and critically analyze literature sources on advanced topics in mathematical and theoretical physics. In addition, students will be able to familiarize themselves with a current research topic and present it in a comprehensible written and oral form. In this way, students deepen their skills in research and presentation techniques, in the preparation of scientific documents and in the structured presentation of complex scientific contexts.

Content

The seminar deals with a specific current research area in mathematical and theoretical physics. Topics from this research area are presented by the students in oral presentations supported by media and discussed in detail. Subsequently, the topics are presented in a written paper, in which the results of the discussion are explicitly addressed.

References

- R. Geroch: "Suggestions for giving talks"
Further recommendations for references and literature will follow in the course.

Specialized Topics of Theoretical Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th/8th semester	at least once a year	**12-PHY-MWPSTP 5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 120 h	
Responsibility: Director of the Institute for Theoretical Physics			
Teaching units (SWS / tutorial hours / private study hours): Seminar “Specialized Topics of Theoretical Physics” (2 SWS / 30 h / 120 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Project work (written report with preparation time 3 weeks, oral presentation of 45 min; ×1)			

Objectives After active participation in the module, students are able to access and critically analyze literature sources on advanced topics in theoretical physics. In addition, students will be able to familiarize themselves with a current research topic and present it in a comprehensible written and oral form. In this way, students deepen their skills in research and presentation techniques, in the preparation of scientific documents and in the structured presentation of complex scientific contexts.

Content The seminar deals with a specific current research area in theoretical physics. Topics from this research area are presented by the students in oral presentations supported by media and discussed in detail. Subsequently, the topics are presented in a written paper, in which the results of the discussion are explicitly addressed.

References - R. Geroch: "Suggestions for giving talks"

Further recommendations for references and literature will follow in the course.

2.6 Non-Physics Electives

Up to 10 CP of any module(s) offered in other study programs can be chosen according to valid cooperation agreements. Further modules can be approved by the examination board upon request.

Introduction to Chemistry

Module type	Recommended for	Module availability	Module number and ECTS
Elective	1st semester	every winter semester	**12-PHY-BIPC** **5 CP**
Workload: 150 h	Tutorial hours: 75 h	Private study hours: 75 h	

Responsibility
Head of the department "Magnetic Resonance of Complex Quantum Solids"

Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Introduction to Chemistry" (3 SWS / 45 h / 45 h)
- Exercise "Introduction to Chemistry" (2 SWS / 30 h / 30 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1)

Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.

Objectives

The students
- extend their basic scientific education;
- develop a basic understanding of the principles, models and methods of chemistry and the underlying nomenclature;
- are able to use their acquired knowledge to participate in advanced courses in this field;

Content

- structure of matter
- chemical bond, chemical equilibrium
- chemical reactions, stoichiometry, acids and bases
- energy of chemical reactions
- chemistry of the main group elements
- chemistry of the transition elements
- organic chemistry, functional groups
- organometallics
- macromolecules

References

- J. E. Brady / J. R. Holum: Chemistry. The Study of Matter and Its Changes, Wiley
- C. E. Mortimer: Chemie: Das Basiswissen der Chemie, Georg Thieme Verlag
- T. L. Brown / H. E. LeMay / B. E. Bursten; Chemistry. The Central Science, Pearson

Numerical Methods in Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	4th semester	every summer semester	**12-PHY-BWNUM** **5 CP**
Workload: 150 h	Tutorial hours: 75 h	Private study hours: 75 h	

Responsibility
Director of the Institute for Theoretical Physics

Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Numerical Methods in Physics" (3 SWS / 45 h / 30 h) - Exercise "Numerical Methods in Physics" (2 SWS / 30 h / 45 h)

Participation requirements
Basic programming knowledge in C or Fortran

Examinations (duration; weighting) and pre-examination requirements
Written exam (90 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

After active participation, students are able to classify and evaluate numerical methods and to understand and critically question their application potential for physical problems. For this purpose, important applications in experimental and theoretical physics are explained using common examples and the specific implementation of numerical algorithms is analysed.

Content

- interpolation and extrapolation methods, sorting methods
- algorithms for extremal optimisation
- linear algebra: inversion of matrices, determination of eigenvalues
- solution method for nonlinear equations: zero determination, fixed point theorem
- numerical differentiation and integration
- "least squares" fitting procedure, statistical methods of analysis
- ("Fast") Fourier transform
- introduction to algebraic computer programs

References

- W.H. Press, S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery, "Numerical Recipes 3rd Edition - The Art of Scientific Computing" (Cambridge University Press, Cambridge, 2007)

External Project Oriented Course – Subject-related Key Qualification

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8th semester	every semester	**12-PHY-BIEPP 5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Dean of Studies for Physics and Meteorology			
Teaching units (SWS / tutorial hours / private study hours) - Laboratory “External Internship” (4 SWS / 60 h / 90 h)			
Participation requirements Participation in the module series 12-PHY-BIEP1 until -BIEP3 and 12-PHY-BIPTP1 until -BIPTP3			
Examinations (duration; weighting) and pre-examination requirements Internship report (preparation time 4 weeks; ×1)			

Objectives

The students

- are given the opportunity to acquire an individual learning biography through an internship in a company/enterprise/research institution/other institutions, which distinguishes them from other Bachelor's graduates;
- apply and expand the skills they have learned in their studies;
- acquire a first orientation on the job market or in research institutions;
- acquire a deeper understanding of physical relationships;
- have learned to implement physical ideas technically;
- can plan and implement a project independently;
- can document the project and its results;
- have learned to work in a team and to communicate scientifically with each other.

Content

The student looks for a business, a company, a research institute or similar, in which she/he applies the analytical and problem-solving skills she/he has acquired in her/his studies to solve problems. The focus here is on expanding her/his competencies. Together with the business, company, research institution or similar, a task is developed that is to be solved within the given workload. This task shows in detail which project is to be worked on, outlines the analytical and problem-solving skills for the student and which competencies the student will acquire in the process. Before the start of the internship, this assignment is submitted to the Dean of Studies, who decides whether the intended internship meets the requirements.

In the external internship, the students work out an individual solution approach in consultation with the supervisor as well as a schedule for carrying out the experiments, calculations or simulations. The internship requires intensive self-study so that the tasks can be worked on with a high degree of independence.

References

None

Women in STEM

Module type	Recommended for	Module availability	Module number and ECTS
elective (SQ)	$4^{th}/6^{th}/8^{th}$ semester	every summer semester	**12-SQM-63** **5 CP**
Workload: 150 h	Tutorial hours: 30 h	Private study hours: 120 h	
Responsibility: Head of the department "Structure and Properties of Complex Materials"			
Teaching units (SWS / tutorial hours / private study hours): - Seminar with Exercise part "Women in STEM" (2 SWS / 30 h / 120 h)			
Participation requirements: English language skills comparable to level B2 according to the Common European Framework of Reference			
Examinations (duration; weighting) and pre-examination requirements: Portfolio (×1)			

Objectives

After active participation in the module, students will be able to assess the underrepresentation of women in certain natural sciences, especially in physics, and at certain qualification levels and to quantify and to understand related social mechanisms. They will be able to analyze approaches to gender equality work and make their own proposals for improving the advancement of women in the interest of equality. The students acquire competences in the areas of argumentation and discussions as well as presentation techniques and are able to work with scientific literature from other disciplines.

Content

Pointing out and analyzing existing structures in the natural sciences with regard to the existing under-representation of women, discussing the relation to the current social situation, also with regard to other underrepresented groups in society, and working out approaches to solutions. History and biographies of women in natural sciences using physics as an example. Students' own experiences from their previous life and studies.

Note on the course: Part of the tutorial time will be held in the form of two block courses.

Notes on the examination: Portfolio consisting of 5 essays on different seminar topics (preparation time 2 weeks each, length 1000 – 1500 words, which corresponds to about 1.5 – 2 pages using common formatting) and a presentation followed by a discussion (preparation time 5 weeks, presentation 20 min, discussion 10 min)

References

Recommendations for further references and literature will follow in the course.

Nachhaltige Entwicklung – Risikobewertung, Methoden und Modelle (Sustainable Development – Risk Assessment, Methods and Models)

Module type	Recommended for	Module availability	Module number and ECTS
elective (SQ)	1st/5th/7th semester	every winter semester	**12-SQM-64** **5 CP**
Workload	Tutorial hours	Private study hours	
150 h	45 h	105 h	

Responsibility
Head of the „Leipziger Initiative für Nachhaltige Entwicklung (LINE)“

Teaching units (SWS / tutorial hours / private study hours)
- Lecture Series “Nachhaltige Entwicklung – Risikobewertung, Methoden und Modelle” (2 SWS / 30 h / 70 h)
- E-Learning Course “Nachhaltige Entwicklung – Risikobewertung, Methoden und Modelle” (1 SWS / 15 h / 35 h)

Participation requirements
Not for students who have already completed the module 12-PHY-BMWBNE1. Language of instruction is German.

Examinations (duration; weighting) and pre-examination requirements
Essay (preparation time 6 weeks; ×1)

Objectives

The students know the basics for considering complex social issues and are able to evaluate socially relevant issues using quantitative models. The students know the basics of sustainable development exemplarily for selected topics of sustainable development considering the Sustainable Development Goals (Agenda 2030). These 17 global goals for sustainable development of the 2030 Agenda were adopted by the global community in 2015. They are addressed to governments worldwide, but also to civil society, the private sector and academia.

In interaction with instructors, students learn:
- how positions can be communicated in a way that is accessible to those outside the field (professional competence, social competence),
- how to look at their own opinions from a variety of perspectives in a new way, how to consider and question them (self-competence),
- to learn and act independently and on their own responsibility (methodological competence).

Content

Lecturers from all faculties of the university give an insight into their current research on social issues. Each contribution highlights where and and how models, data, and their quantitative analysis can be used to better understand the problem and to develop strategies for solving the problem while accounting for sustainability. The module will conclude with an essay on a topic of the student's choice.

References

Recommendations for further references and literature will follow in the course.

Alternatively, the module “Handlungskompetenz für nachhaltige Entwicklung – Grundlagenmodul” (12-PHY-BMWBNE1) can be chosen. However, only 1 of the 2 modules can be completed in this study program.

Handlungskompetenz für nachhaltige Entwicklung – Grundlagenmodul (Action Competence for Sustainable Development – Fundamental Module)

<table>
<tr><td>Module type
elective</td><td>Recommended for
5th/7th semester</td><td>Module availability
every winter semester</td><td rowspan="2">Module number and ECTS
12-PHY-BMWBNE1
10 CP</td></tr>
<tr><td>Workload
300 h</td><td>Tutorial hours
75 h</td><td>Private study hours
225 h</td></tr>
<tr><td colspan="4">Responsibility
Head of the „Leipziger Initiative für Nachhaltige Entwicklung (LINE)“</td></tr>
<tr><td colspan="4">Teaching units (SWS / tutorial hours / private study hours)
- Lecture Series “Nachhaltige Entwicklung – Risikobewertung, Methoden und Modelle” (2 SWS / 30 h / 70 h)
- E-Learning Course “Nachhaltige Entwicklung – Risikobewertung, Methoden und Modelle” (1 SWS / 15 h / 35 h)
- Seminar “Praxisseminar I” (1 SWS / 15 h / 60 h)
- Seminar “Praxisseminar II” (1 SWS / 15 h / 60 h)</td></tr>
<tr><td colspan="4">Participation requirements
Not for students who have already completed the module 12-SQM-64. Language of instruction is German.</td></tr>
<tr><td colspan="4">Examinations (duration; weighting) and pre-examination requirements
Oral presentation (45 min) and written report (preparation time 4 weeks); weighting ×1</td></tr>
</table>

Objectives

The students know the basics for considering complex social issues and are able to evaluate socially relevant issues using quantitative models. The students know the basics of sustainable development and apply acquired competencies in an exemplary manner to selected topics of sustainable development, taking into account the Sustainable Development Goals. These 17 global goals for sustainable development of the 2030 Agenda were adopted by the global community in 2015. They are addressed to governments worldwide, but also to civil society, the private sector and academia.

In interaction with instructors, students learn:

- communicate their points of view in such a way that they can be understood by non-experts (professional competence, social competence),
- to take a fresh look at their own points of view from a variety of perspectives, to consider and to question them (self-competence),
- to learn and act independently and on their own responsibility (methodological competence),
- the use of data, models and statistics to develop and evaluate concrete approaches to actions (mathematical-methodical competence).

Content

Lecturers from all faculties of the university give an insight into their current research on social issues. Each contribution highlights where and and how models, data, and their quantitative analysis can be used to better understand the problem and to develop strategies for solving the problem while accounting for sustainability. The module will conclude with an essay on a topic of the student's choice.
In the first Praxisseminar, solution strategies are developed for selected examples of socially relevant problems. The Seminar is completed with an essay (written elaboration) on a topic of the student's choice. The results developed in this essay are presented, discussed and validated in a presentation in the second Praxisseminar.

In the module, sustainable action is thus presented in writing in relation to socially relevant issues, the own results are presented in an oral scientific discussion and feedback is given on the results of the other participants.

This fundamental module lays the foundation on which more advanced courses for the interdisciplinary university certificate "Action Competence for Sustainable Development" build on. In total, the certificate is based on 3 modules with a total of 20 CP: fundamental module, advanced module and real lab.

References Recommendations for further references and literature will follow in the course.

Alternatively, the module “Nachhaltige Entwicklung – Risikobewertung, Methoden und Modelle” (12-SQM-64) can be chosen. However, only 1 of the 2 modules can be completed in this study program.

Deutschkurs A1.1 (German Course A1.1)

Module type	Recommended for	Module availability	Module number and ECTS
elective	1st semester	every winter semester	**30-PHY-BIPSQ1** **5 CP**
Workload: 150 h	Tutorial hours: 90 h	Private study hours: 60 h	
Responsibility: Studienkolleg Sachsen			
Teaching units (SWS / tutorial hours / private study hours): - Language course "Grundkurs Deutsch für Studierende ohne Vorkenntnisse A1.1" (6 SWS / 90 h / 60 h)			
Participation requirements: Participation in the initial language test (first lecture); language of instruction is German			
Examinations (duration; weighting) and pre-examination requirements: Komplexprüfung – Combined Exam (60 min; written part 45 min and oral part 15 min; ×1)			

Objectives

Students acquire basic knowledge of the German language up to level A1.1 (partial achievement of level A1 of the Common European Framework of Reference). Students develop elementary skills in the areas of reading comprehension, listening comprehension, and oral and written communication in German. As a supplement to the subject-related part of the bachelor's program in English, the German course enables better access to the new cultural environment and facilitates integration into everyday study life.

Content

At the end of the module, students achieve level A1.1, a partial achievement of level A1 of the Common European Framework of Reference. In the language course, elementary skills are developed in the areas of reading comprehension, listening comprehension and oral and written communication in German. communication in German. The course is based on a course book and workbook, the purchase of which is strongly recommended.

A language test will be taken in the first class. If students already have previous knowledge of the German language, they can, depending on the available places, participate directly in the module "Deutschkurs A2" or in the German courses of the levels B1 / B2 / C1.

Note on the examination: The "Komplexprüfung" (combined exam) consists of a written part (45 min) and an oral part (15 min). Points are awarded for both parts and a grade is given according to the total number of points.

References

In the course uses a course- and workbook is used. The purchase is strongly recommended. Recommendations for further references and literature will follow in the course.

Deutschkurs A1.2 (German Course A1.2)

Module type	Recommended for	Module availability	Module number and ECTS
elective	4th semester	every summer semester	**30-PHY-BIPSQ2** **5 CP**
Workload: 150 h	Tutorial hours: 90 h	Private study hours: 60 h	
Responsibility: Studienkolleg Sachsen			
Teaching units (SWS / tutorial hours / private study hours): - Language course “Aufbaukurs Deutsch für Studierende A1.2” (6 SWS / 90 h / 60 h)			
Participation requirements: Completion of the module 30-PHY-BIPSQ1; language of instruction is German			
Examinations (duration; weighting) and pre-examination requirements: Written Exam (90 min; ×3) and Oral Exam (15 min; ×1)			

Objectives

Students acquire further basic knowledge of the German language and reach level A1 of the Common European Framework of Reference for Languages when completing the module.

Students can understand and use familiar, everyday expressions and very simple sentences needed in daily life. They can introduce themselves and others and ask and answer questions about themselves and others. They can express themselves on a simple level provided the other person talks slowly and clearly and is prepared to help.

Access to the new cultural environment and integration into the daily study routine will be further improved.

Content

At the end of the module students reach level A1 of the Common European Framework of Reference for Languages. In the language course the elementary skills in the areas of reading comprehension, listening comprehension and oral and written communication in German are further developed.

The language course includes the following contents:

- reading and understanding short, simple texts, which contain a highly frequented vocabulary and a certain amount of internationally known words
- spoken comprehension, when spoken very slowly and carefully and when long pauses allow time to grasp the meaning
- to communicate in a simple way, but communication may require slowly repeating, rephrasing and corrections
- asking and answering simple questions, phrasing of or reacting to simple questions
- cope with very short contact conversations by using common polite forms of greeting or salutation
- issuing invitations and apologies and responding to them
- communicate wishes and concerns in a simple, direct exchange of limited information on familiar matters
- ask for or give information in writing about the person or a simple matter
- learning limited vocabulary related to specific everyday needs
- introduction to first simple grammatical structures and sentence patterns
- learn the pronunciation of a very limited repertoire in order to be understood despite a noticeable accent

The course is based on a course book and workbook, the purchase of which is strongly recommended.

References

In the course uses a course- and workbook is used. The purchase is strongly recommended. Recommendations for further references and literature will follow in the course.

Deutschkurs A2 (German Course A2)

Module type	Recommended for	Module availability	Module number and ECTS
elective	5th semester	every winter semester	**30-PHY-BIPSQ3 5 CP**
Workload 150 h	Tutorial hours 90 h	Private study hours 60 h	
Responsibility Studienkolleg Sachsen			
Teaching units (SWS / tutorial hours / private study hours) - Language course “Aufbaukurs Deutsch für Studierende A2” (6 SWS / 90 h / 60 h)			
Participation requirements Completion of the modules 30-PHY-BIPSQ1 and 30-PHY-BIPSQ2 or an equivalent result for direct entry into the module 30-PHY-BIPSQ3 in the initial language test; language of instruction is German			
Examinations (duration; weighting) and pre-examination requirements Written Exam (90 min; ×3) and Oral Exam (15 min; ×1)			

Objectives

Students expand their basic knowledge of the German language and achieve level A2 of the Common European Framework of Reference for Languages when completing the module.
Students can understand sentences and frequently used expressions related to areas of most immediate relevance (e.g. personal and family information, shopping, work, local area). They can communicate in simple, routine situations involving a simple and direct exchange of information on familiar and routine matters. They can describe in simple terms their background and education, the immediate environment and matters in areas of immediate need.
Access to the new cultural environment will be further facilitated, thus giving them access to the academic offers of Leipzig University in the future.

Content

At the end of the module students reach level A2 of the Common European Framework of Reference for Languages. In the language course the basic skills in reading comprehension, listening comprehension and oral and written communication in German are improved.

The language course includes the following contents:
- reading and understanding (uncomplicated) factual texts on topics related to own interests and areas of expertise
- find out specific information in simple texts and recognize structures
- understanding short oral texts or narratives
- understanding the most important points when talking in clearly articulated standard language about familiar things that are normally encountered at work, in education or during leisure time
- practising simple routine conversations and easy communications in structured situations and short conversations, asking and answering questions, expressing personal opinions and exchanging information on familiar topics
- giving or asking for simple information of immediate relevance in personal letters and messages
- expressing in writing on a simple matter
- practising simple grammatical structures and sentence patterns
- improving pronunciation in general in order to be understood despite a noticeable accent

The course is based on a course book and workbook, the purchase of which is strongly recommended.

References

In the course uses a course- and workbook is used. The purchase is strongly recommended. Recommendations for further references and literature will follow in the course.

2.7 Physics Electives – Introduction into Specialization

Please note, that not all electives can be offered once a year. Check out the Course Catalogue for the list of modules being offered in the upcoming semester.

Introduction to Photonics I

Module type	Recommended for	Module availability	Module number and ECTS
elective	5th/7th semester	every winter semester	**12-PHY-BW3MO1** **5 CP**
Workload: 150 h	Tutorial hours: 45 h	Private study hours: 105 h	
Responsibility: Head of the department “Molecular Nanophotonics”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Introduction to Photonics I” (2 SWS / 30 h / 45 h) - Exercise “Introduction to Photonics I” (1 SWS / 15 h / 60 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (30 min; ×1)			

Objectives

The studens
- get introduced to the principles of optics on a deeper level;
- learn special calculus for optics;
- obtain an overview of the building blocks that actively and optically manipulate light;
- gain insight into the properties of single photons and the preparation of them;
- learn basic concepts of quantum optics and quantum cryptography.

Content

During the courses of the module, students deepen their knowledge of ray-, wave and electromagnetic optics. In particular active optical building blocks, for example belonging to the field of electro- and acusto-optics, will be discussed.

Furthermore, the students will be introduced to the field of photon-optics and problems of photon statistics, single photon sources and quantum optics/quantum cryptography will be discussed.

During the seminar, calculations concerning up to date research will be discussed and using examples the experimental realisation of various measuring techniques will be explained.

References

- B. E. A. Saleh / M. C. Teich: Fundamentals of Photonics, Wiley
- D. Meschede: Optics, Light and Lasers: The Practical Approach to Modern Aspects of Photonics and Laser Physics, Wiley-VCH
- L. Mandel / E. Wolf: Optical Coherence and Quantum Optics, Cambridge University Press
- E. Hecht: Optics, Addison-Wesley

Introduction to Polymer Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8th semester	irregular cycle	**12-PHY-BMWMO2** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department "Molecular Nanophotonics"			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Introduction to Polymer Physics" (2 SWS / 30 h / 45 h) - Seminar "Introduction to Polymer Physics" (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (20 min; ×1) *Pre-examination requirements: Successful presentation in the seminar (20 min)*			

Objectives

The students acquire knowledge about the structure and the structural and dynamic properties of polymers as well as about physical methods that are used for the experimental analysis and investigation of polymers. With the gained knowledge, students will be able to understand, discuss and evaluate state of the art literature in the field of polymer science. They can present a method of polymer physics in a lecture and find, select and classify the corresponding literature.

Content

Lecture: The starting point of the lecture is the structure and dynamics of polymers. Based on these properties, different experimental methods for their investigation are introduced. The following topics are covered:

Structure of polymers:
- Structure and dynamics of polymers
- Glass transition, semi-crystalline systems, mesophase separation

Structure elucidation methods:
- Infrared spectroscopy
- Atomic force microscopy
- X-ray and neutron scattering

Methods for the determination of dynamics:
- Dielectric spectroscopy
- Shear rheology (mechanical spectroscopy)
- Photon correlation spectroscopy

Seminar: Analyses of publications and presentation on selected methods.

References

- G. Strobl: The Physics of Polymers: Concepts for Understanding Their Structures and Behavior (Springer)
- B. Stuart: Infrared Spectroscopy: Fundamentals and Applications (Wiley)

Introduction to Computer Simulation I

Module type	Recommended for	Module availability	Module number and ECTS
elective	$5^{th}/7^{th}$ semester	every winter semester	**12-PHY-BW3CS1** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department “Computer oriented quantum field theory”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Introduction to Computer Simulation I” (2 SWS / 30 h / 45 h) - Exercise “Introduction to Computer Simulation I” (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Written exam (60 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

After active participation in this module, the students are able to classify the essential concepts and methods of computer simulations and to analyse different strategies for problem solving. They are familiar with common procedures and their application to examples in statistical physics. The students are able to develop their own programme codes for model problems, test their performance and check the validity by comparing them with known limiting cases.

Content

Molecular modelling of many-particle systems:

- Basic concepts of statistical physics (statistical totals and averaging, distribution and correlation functions, thermodynamic functions and transport coefficients)
- Computer simulations of many-particle systems (basic methods and algorithms, statistical-mechanical evaluations)
- Molecular dynamics (MD) in the NVE ensemble and with thermalisation (NVT)
- Metropolis Monte-Carlo (MC)
- Evaluations and relation to experiment
- Applications of MD and MC methods to simple systems

References

- M.P. Allen and D.J. Tildesley, Computer simulation of liquids, Clarendon Press, Oxford, 1987.
- R. Haberlandt, S. Fritzsche, G. Peinel, K. Heinzinger, Molekulardynamik - Grund- lagen und Anwendungen, mit Kapitel von H.L. Vörtler, Abriss der Monte-Carlo- Methode, Vieweg , Wiesbaden, 1995
- D. Frenkel and B. Smit, Understanding Molecular Simulations; From Algorithms to Applications, Academic Press, San Diego, London, 2002

Experimental Methods of Biophysics

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8 semester	irregular cycle	**12-PHY-BMWEMB** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	

Responsibility
Head of the department "Molecular Biophysics"

Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Experimental Methods of Biophysics" (2 SWS / 30 h / 45 h)
- Seminar "Experimental Methods of Biophysics" (2 SWS / 30 h / 45 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Oral exam (20 min; ×1)

Pre-examination requirements: Successful presentation in the seminar (20 min)

Objectives

The students acquire knowledge of basic physical techniques that are used for the analysis and investigation of biological systems. With the acquired knowledge, the students receive an introduction to the structure of biological matter. They will be able to understand, discuss and evaluate literature in which biophysical techniques are applied. The students can present a method of biophysics in a lecture and obtain, select and classify the corresponding literature.

Content

Lecture: Starting point of the lecture are different methods of biophysics for the investigation of structure and dynamics of biological systems and processes. The following topics are covered:
- Structure of cells
- Structure and dynamics of biomolecules
- Production and separation of biological molecules and complexes
- Mass spectrometry
- Optical spectroscopy (absorption spectroscopy, circular dichroism, fluorescence spectroscopy, vibrational spectroscopy)
- Light microscopic techniques
- Force spectroscopy
- Nuclear magnetic resonance spectroscopy
- Light and X-ray scattering
- Structure determination techniques (electron microscopy, X-ray crystallography)
- Calorimetric methods
- Numerical methods of structure modelling and bioinformatics

Seminar: Analysis of publications and presentation of selected methods.

References

- B. E. A. Saleh / M. C. Teich: Fundamentals of Photonics, Wiley
- D. Meschede: Optics, Light and Lasers: The Practical Approach to Modern Aspects of Photonics and Laser Physics, Wiley-VCH
- L. Mandel / E. Wolf: Optical Coherence and Quantum Optics, Cambridge University Press
- E. Hecht: Optics, Addison-Wesley

Introduction to Medical Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8th semester	every semester	**12-PHY-BMWMED1 5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Head of the department “Biotechnology and Biomedicine”			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Experimental Methods of Biophysics” (2 SWS / 30 h / 45 h) - Seminar “Experimental Methods of Biophysics” (2 SWS / 30 h / 45 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Oral exam (20 min; ×1) *Pre-examination requirements: presentation (20 min)*			

Objectives

After successfully completing this course, students will be able to understand and classify physical models of biological and medical phenomena. Students acquire knowledge in the field of the physical foundations of life, the functioning of the body and their medical relevance. They will be able to understand, discuss and evaluate physical processes of the body. They will be able to apply the knowledge they have acquired about the function and biomechanics of the body, as well as methods for researching the body and the use of biomaterials to medical issues and transfer them to new problems.

Content

- biomechanics of the body: theory of elasticity,
- bones: structure and function,
- function of muscles and joints,
- circulation of blood: functioning and hydrodynamics of the blood,
- the physics of hearing: introduction to acoustics, wave equation for sound,
- acoustics of the ear: structure and functioning, impedance matching of the ear,
- the physics of the eye: structure of the eye, function of the fovea,
- methods for researching tissues and active substances outside the body, use of biomaterials in medicine

References

Recommendations for references and literature will follow in the courses.

Semiconductor Physics I

Module type	Recommended for	Module availability	Module number and ECTS
elective	5th/7th semester	every winter semester	**12-PHY-BW3HL1 10 CP**
Workload: 300 h	Tutorial hours: 75 h	Private study hours: 225 h	

Responsibility
Head of the "Semiconductor Physics Group"
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Semiconductor Physics I" (4 SWS / 60 h / 120 h) - Exercise "Semiconductor Physics I" (1 SWS / 15 h / 105 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Bi-weekly homework assignments related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

The students

- build on a solid basic education in physics to explore a field of research at one of our physics institutes;
- acquire the basics of semiconductor physics.

Content

The basics of semiconductor physics are explained, including crystal structure, lattice vibrations, band structure, doping, transport phenomena, surfaces, optical properties, charge carrier recombination and heterostructures.

References

- M. Grundmann, The Physics of Semiconductors, Springer
- K. Seeger, Halbleiterphysik I und II, Vieweg und Teubner

Laboratory Work in Semiconductors I

<table>
<tr><td>Module type
elective</td><td>Recommended for
$5^{th}/7^{th}$ semester</td><td>Module availability
every winter semester</td><td rowspan="2">Module number and ECTS
12-PHY-BW3HL2
5 CP</td></tr>
<tr><td>Workload
150 h</td><td>Tutorial hours
30 h</td><td>Private study hours
120 h</td></tr>
<tr><td colspan="4">Responsibility
Head of the “Semiconductor Physics Group”</td></tr>
<tr><td colspan="4">Teaching units (SWS / tutorial hours / private study hours)
- Laboratory “Laboratory Work in Semiconductors I” (2 SWS / 30 h / 120 h)</td></tr>
<tr><td colspan="4">Participation requirements
None</td></tr>
<tr><td colspan="4">Examinations (duration; weighting) and pre-examination requirements
Lab reports (8 experiments, 4 written reports (preparation time 4 weeks), 8 oral exams; ×1)</td></tr>
</table>

Objectives

The students

- acquire theoretical and experimental knowledge of basic fabrication and characterisation methods in modern semiconductor physics;
- can independently apply and evaluate standard methods of experimental semiconductor physics;
- learn to familiarize themselves with problems in semiconductor physics, to solve them creatively and to present and defend the obtained results.

Content

This lab course accompanies the module Semiconductor Physics I. Experiments are carried out on state-of-the-art equipment of the semiconductor physics group, which is also in daily use in current research projects.

The module builds on the competences gained in this bachelor programme on performing experiments and complements the qualification in the field of semiconductor physics.

The students carry out 8 different experiments per semester according to a specified schedule. The lab course HLP (I) covers the growth of thin films (Pulsed Laser Deposition) and basic characterisation methods of modern semiconductor research on structure (SEM, RHEED, XRD), electrical transport (Hall effect), radiative recombination (photoluminescence), dielectric function (ellipsometry) and ferroic properties (ferroelectric and magnetic hysteresis).

The preparation for the experiments is done with the help of detailed scripts. The experiments are carried out under the guidance of a supervisor. The evaluation of the experiments is carried out by means of a report and an oral test - each of which is graded.

References

- M. Grundmann: The Physics of Semiconductors, An Introduction including Devices and Nanophysics Springer, Heidelberg, 2006; Revised and extended 2nd edition 2009.

Surface Physics, Nanostructures and Thin Films

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8 semester	irregular cycle	**12-PHY-BMWOFP1** **5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Head of the department “Surface Physics”			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Surface Physics, Nanostructures and Thin Films” (2 SWS / 30 h / 45 h) - Seminar “Surface Physics, Nanostructures and Thin Films” (2 SWS / 30 h / 45 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Oral exam (30 min; ×1) *Pre-examination requirements: Successful presentation in the seminar (30 min)*			

Objectives

After active participation in the module, the students have a comprehensive overview on the physical fundamentals of surfaces, nanostructures and thin films, as well as on their application in future-oriented areas. Based on this, they will be able to further develop their education independently in the mentioned areas by means of technical literature, in order to finally work independently. On the other hand, the participants are familiarised with the central "soft skills" of literature research, preparation of a scientific presentation and presentation techniques.

Content

Lecture:

- crystal structure, thermodynamics, electronic properties of surfaces
- surface kinetics, structure formation, surface reactions
- functionalisation of surfaces and interaction with biological cells and tissues, biocompatibility
- preparation and characterisation of well-defined surfaces
- nanoclusters, -rods and -tubes, synthesis (miniaturisation - top-down process, printing / self-organisation - bottom-up process), structure, thermodynamics, kinetics, electronic and magnetic properties
- quantum mechanical basics of low-dimensional nanostructures
- functional nanostructures for biological and medical applications
- physical fundamentals of thin films, growth modes, epitaxy, mechanical stresses in thin films, ion and electron beam assisted methods of synthesis and analysis, functional thin films

Seminar:

Accompanying the lecture, presentations are assigned on special topics in the field of application of functional surfaces, thin films and nanostructures. The focus is on applications in the fields of medicine, energy and information processing.

References

- H. Ibach, "Physics of Surfaces and Interfaces", Springer 2006
- B. Bushan, "Handbook of Nanotechnology", Springer, 2017

Plasma Physics, Thin Film Deposition and Characterization

Module type	Recommended for	Module availability	Module number and ECTS
elective	5th/7th semester	every winter semester	**12-PHY-BMWIOM2 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	

Responsibility
Head of the department “Applied Physics”
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Plasma Physics, Thin Film Deposition and Characterization” (2 SWS / 30 h / 45 h) - Seminar “Plasma Physics, Thin Film Deposition and Characterization” (2 SWS / 30 h / 45 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1)

Objectives

The students
- gain an overview of the generation of plasmas and their interaction with surfaces
- get to know typical applications of plasmas and will apply basic measurement methods professionally
- get an introduction to modern procedures for the experimental production of thin films
- systematically develop basic principles of advanced methods for the characterisation of surfaces

Content

- history of Plasma Physics
- fundamentals of plasma physics
- plasma-wall interaction
- plasma and ion sources
- deposition technologies for thin films
- physics of thin films
- delected methods of surface and thin film analysis

References

- F.F. Chen, Plasma Physics and Controlled Fusion, Plenum Press, New York, 1984.
- Lieberman, M.A., Lichtenberg, A.J.: "Principles of Plasma Discharges and Materials Processing", Wiley 1994
- H. Bubert, H. Jenett (Eds.) "Surface and Thin Film Analysis, Principles, Instrumentation, Application", Wiley-VCH Verlag 2002
- H. Ibach, "Physics of Surfaces and Interfaces", Springer, 2006

Microstructural Characterization

Module type	Recommended for	Module availability	Module number and ECTS
elective	$6^{th}/8^{th}$ semester	every summer semester	**12-PHY-BMWIOM3 5 CP**
Workload: 150 h	Tutorial hours: 45 h	Private study hours: 105 h	
Responsibility: Head of the department “Applied Physics”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Microstructural Characterization” (2 SWS / 30 h / 45 h) - Seminar “Microstructural Characterization” (1 SWS / 15 h / 60 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (30 min; ×1) *Pre-examination requirements: Successful presentation in the seminar (25 min)*			

Objectives

Students acquire knowledge of scientific analysis methods (based on electron microscopy techniques) used in micro- and nanostructure characterisation of materials. With the acquired knowledge, the students are able to select optimal analytical methods for the structural and chemical characterisation of complex materials. They deepen their knowledge by giving a presentation in the seminar and by the demonstration of various techniques on scientific equipment.

Content

Basics of transmission and scanning electron microscopy (structure, e-sources, e-optics, resolution); sample preparation (conventional, FIB); analytical methods (imaging, diffraction, image simulation); analytical electron microscopy (EDX, EELS); examples from own research

References

- D. Brandon and W.D. Kaplan, Microstructural Characterization of Materials, 2nd Edition, John Willey and Sons Ltd., 2008
- R.F. Egerton, Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM, Springer International Publishing, 2016
- D.B. Willams and C.B. Carter, Transmission electron microscopy: A Textbook for Materials Science, Plenum Publishing Corporation, 2009
- J.M. Zhou, J.C.H. Spence, Advanced Transmission Electron Microscopy: Imaging and Diffraction in Nanoscience, Springer-Verlag New York, 2017

Quantum Matter

Module type	Recommended for	Module availability	Module number and ECTS
elective	$5^{th}/7^{th}$ semester	every winter semester	**12-PHY-BMWQMAT** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	

Responsibility
Head of the department "Quantum Optics"
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Quantum Matter" (2 SWS / 30 h / 45 h) - Seminar "Quantum Matter" (2 SWS / 30 h / 45 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1) *Pre-examination requirements: Presentation in the seminar (25 min) with written summary (3 weeks)*

Objectives

The students are introduced into a current research area of the physics institutes and expand existing knowledge of fundamental physical concepts of quantum mechanics and optics. With the acquired knowledge, the students are enabled to understand, discuss and evaluate the specialist literature from the field of modern atomic physics. They can present relevant examples from this field in a lecture and obtain, select and classify the relevant literature.

Content

In this module, various experiments in modern atomic physics are discussed, including those from the following areas:

- cooling atomic gases down to a few nanokelvin
- atomic Bose-Einstein condensates and degenerate Fermi gases
- BEC-BCS crossover, polarons and quantum thermodynamics
- atoms in optical lattices: quantum simulation of Bose-Hubbard Hamiltonians
- hybrid atom-solid systems: cavity-QED for fundamental tests of quantum mechanics
- precision measurements with atomic sensors: electromagnetism, gravitation and fundamental constants

References

References will be annouced in the lectures

Quantum Physics of Nanostructures

Module type	Recommended for	Module availability	Module number and ECTS
elective	$5^{th}/7^{th}$ semester	irregular cycle	**12-PHY-BW3QN1** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Director of the Institute of Theoretical Physics			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Quantum Physics of Nanostructures" (3 SWS / 45 h / 45 h) - Exercise "Quantum Physics of Nanostructures" (1 SWS / 15 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral presentation (30 min; ×1)			

Objectives

Students learn the essential concepts and theoretical description of quantum effects on the nanoscale.

Content

- quantum wires and quantum dots
- quantum interference
- dephasing, i.e. transition from quantum mechanical to classical behaviour
- Aharonov-Bohm effect and persistent currents
- Graphene
- Quantum Hall effect
- mesoscopic superconductivity

References

- Y. Imry, Introduction to mesoscopic physics, Oxford University Press
- T. Ihn, Semiconductor Nanostructures, Oxford University Press
- E. Akkermans and G. Montambaux, Mesoscopic Physics of Electrons and Photons, Cambridge University Press
- Y.V. Nazarov and Y.M. Blanter, Quantum Transport: Introduction to Nanoscience, Cambridge University Press

Quantum Technology 1

Module type	Recommended for	Module availability	Module number and ECTS
elective	5th/7th semester	every winter semester	**12-PHY-BMWQT1 5 CP**
Workload	**Tutorial hours**	**Private study hours**	
150 h	45 h	105 h	
Responsibility			
Head of the department “Applied Quantum Systems”			
Teaching units (SWS / tutorial hours / private study hours)			
- Lecture “Ion beams and their use in material analysis and modification” (2 SWS / 30 h / 45 h) - Seminar “Ion beams and their use in material analysis and modification” (1 SWS / 15 h / 60 h)			
Participation requirements			
None			
Examinations (duration; weighting) and pre-examination requirements			
Oral exam (30 min; ×1) *Pre-examination requirements: Presentation in the seminar (15 min)*			

Objectives

After successful participation in the module, students are able

- to - building on a solid basic education in physics - introduce themselves into a current application of ion beams in science and technology, and to present it to other students and scientists
- to explain and to evaluate methods and challenges of ion beam technology
- to apply the acquired knowledge to hypothetical application scenarios

Content

The lecture deals with the generation and application of ion beams. In the field of ion implantation, the classical applications in the field of semiconductor technology are demonstrated and at the same time the foundations for understanding the application of ion beams for the generation of quantum mechanical systems are laid. Another focus of the lecture is on the teaching of ion beam analysis techniques.

Topics: accelerator technology, interaction of ions with matter, ion implantation, ion beam analysis

References

- Schatz/Weidinger "Nukleare Festkörperphysik", Teubner
- Demtröder "Experimentalphysik 4", Springer
- Further references will be annouced in the lectures.

Quantum Technology – Lab Course

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/8th semester	every summer semester	**12-PHY-BMWQTPR** **5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	
Responsibility Head of the department "Applied Quantum Systems"			
Teaching units (SWS / tutorial hours / private study hours) - Laboratory "Quantum Technology Lab Course" (3 SWS / 45 h / 105 h)			
Participation requirements Participation in the module 12-PHY-BMWQT1			
Examinations (duration; weighting) and pre-examination requirements Presentation (30 min) with written summary (3 weeks); ×1 *Pre-examination requirements: Lab reports*			

Objectives

After successful participation in the lab course, students are able

- to apply ion beam analysis, modification and optical measurement methods independently
- to recognise new informations from physical measurements, discuss them in a coherent work and present them to other students and scientists
- organise themselves in a group and coordinate tasks

Content

The focus of the lab course is on experiments to deepen the knowledge acquired in the corresponding lectures by practical application. For this purpose, the students are provided with material that serves to prepare them for experiments in the field of ion radiation and optics at defect centres. In addition, a more in-depth introduction to the measurement programmes required for evaluation takes place is given.

Topics: accelerator technology, interaction of ions with matter, ion implantation, ion beam analysis and modification methods, methods for generating and characterising individual defect centres, confocal microscopy

References

- Schatz/Weidinger "Nukleare Festkörperphysik", Teubner
- Demtröder "Experimentalphysik 4", Springer
- Further material prepared by the Applied Quantum Systems group

Quantum Communication

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8th semester	once a year	**12-PHY-BMWQC1** **5 CP**
Workload: 150 h	Tutorial hours: 45 h	Private study hours: 105 h	

Responsibility
Head of the department “Solid-State Based Quantum Information”
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Quantum Communication” (2 SWS / 30 h / 70 h) - Seminar “Quantum Communication” (1 SWS / 15 h / 35 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1) *Pre-examination requirements: Solution of weekly exercises on the module content, for which points will be awarded. Prerequisite for admission to the exam is 1) the achievement of 50% of the possible points of the semester and 2) one presentation of a solution to an exercise.*

Objectives

The students
- know the advantages that quantum communication can offer compared to classical communication
- are able to describe quantum mechanical processes in quantum communication physically and mathematically
- understand the advantages and disadvantages of different hardware platforms and experimental techniques for the realization and optimization of quantum communication processes
- have studied current literature on quantum communication and thus gained an overview of the current state of the art and open questions

Content

- introduction to quantum mechanics and optics topics relevant to quantum communication
- description, generation and use of quantum entanglement in quantum communication
- discussion of basic quantum communication protocols
- problems with quantum communication over long distances and approaches for quantum repeaters
- promising hardware platforms for the realization of quantum communication (photons, solid-state spins, quantum dots, trapped atoms)

References

- Nielsen, M. und Chuang, I.Einführung in die Quantum Informationsverarbeitung: “Quantum Computation and Quantum Information”
- Bassoli, R. et. al., “Quantum Communication Networks”
- Peter Rohde, “The Quantum Internet”
- Azuma, K. et al., “Quantum repeaters: From quantum networks to the quantum internet”, arxiv.org (2022)
- Ruf, M. et al., “Quantum networks based on color centers in diamond” Journal of Applied Physics 130, 070901 (2021)

Quantum Sensing

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8th semester	once a year	**12-PHY-BMWQS1** **5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	
Responsibility Head of the department “Solid-State Based Quantum Information”			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Quantum Sensing” (2 SWS / 30 h / 70 h) - Exercise “Quantum Sensing” (1 SWS / 15 h / 35 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Oral exam (30 min; ×1) *Pre-examination requirements: Solution of weekly exercises on the module content, for which points will be awarded. Prerequisite for admission to the exam is 1) the achievement of 50% of the possible points of the semester and 2) one presentation of a solution to an exercise.*			

Objectives

The students
- have basic knowledge of quantum mechanical principles and can use this to define quantum sensors
- are able to determine how environmental parameters, e.g. magnetic fields, change the states of quantum sensors and how the readout of these parameters can be realized using measurement protocols
- are able to describe the known realizations of quantum sensors with the respective mode of operation and compare them with each other on the basis of properties such as coherence and sensitivity
- are able to analyze how the sensitivity of quantum sensors can be increased by applying quantum mechanical principles, e.g. entanglement and squeezing, and how this can be applied to different platforms
- can name specific applications of quantum sensors and describe the state of the art

Content

- fundamentals of quantum mechanics
- definition and basic principles of quantum sensors (e.g. coherence, measurement protocols, noise, sensitivity)
- examples of quantum sensors and how they work (e.g. atom interferometry, atomic vapor cells, superconducting structures, NV centers in diamonds)
- applications of quantum sensors (e.g. gravity gradiometer, measurement of magnetic fields in the brain MEG, detection of bio-magnetism and temperature in cells with nanometer resolution, single molecule magnetic resonance)
- advanced measurement principles of quantum sensors (utilization of entanglement, squeezing, quantum memory and quantum error correction)

References

- C. Degen et. al, Quantum Sensing, Rev. Mod. Phys. 89, 035002, 2017
- D. Budker and D. F. J. Kimball, Optical Magnetometry (Cambridge University Press, Cambridge, UK) 2013

Spin Resonance I

Module type	Recommended for	Module availability	Module number and ECTS
elective	$5^{th}/7^{th}$ semester	every winter semester	**12-PHY-BW3MQ1** **5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Head of the department "Magnetic Resonance of Complex Quantum Solids"			
Teaching units (SWS / tutorial hours / private study hours) - Lecture "Spin Resonance I" (2 SWS / 30 h / 45 h) - Exercise "Spin Resonance I" (2 SWS / 30 h / 45 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (90 min; ×1)			

Objectives

The students
- acquire basic knowledge in the field of spin resonance
- learn the basics of the quantum theory of spin resonance
- learn the basics of experimental proof

Content

- Dirac formulation of the quantum theory of spin resonance
- density operator formalism for spin resonance
- fundamentals of high-frequency measurements
- electronic detection and digital recording of near-noise high-frequency signals

References

- Slichter, C.P. Principles of Magnetic Resonance
- M. H. Levitt, Spin Dynamics

Superconductivity I

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/8th semester	every summer semester	**12-PHY-BW3SU1** **5 CP**
Workload: 150 h	Tutorial hours: 45 h	Private study hours: 105 h	

Responsibility
Head of the department "Superconductivity and Magnetism"
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Superconductivity I" (2 SWS / 30 h / 70 h) - Exercise "Superconductivity I" (1 SWS / 15 h / 35 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (45 min; ×1) *Pre-examination requirements: Homework on four exercise sheets. Points are awarded for the assessed exercise sheets. 50% of the total points have to be achieved as prerequisite for admission to the exam.*

Objectives

The students
- build on a solid basic education in physics to explore a field of research at the institutes of physics
- become familiar with the most important phenomena of superconductivity
- become familiar with typical applications of superconductivity

Content

- phenomenology of Type I and Type II superconductors
- London theory of superconductivity
- Ginzburg-Landau theory
- problem of anchoring flux lines and their significance for applications

References

- D.R. Tilley and J. Tilley: Superfluidity and Superconductivity
- M. Tinkham: Introduction to Superconductivity
- R.P. Huebener: Magnetic Flux Structures in Superconductors
- P.G. de Gennes: Superconductivity of Metals and Alloys
- W. Buckel und R. Kleiner, Supraleitung

Fundamentals of Magnetism

Module type	Recommended for	Module availability	Module number and ECTS
elective	5/6/7/8th semester	at least once in two years	**12-PHY-BMWSUM 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department "Superconductivity and Magnetism"			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Fundamentals of Magnetism" (2 SWS / 30 h / 45 h) - Exercise "Magnetism" (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (30 min; ×1) *Pre-examination requirements: Bi-weekly homework assignments related to the module content. Points are awarded for solutions. 50% of the total points have to be achieved as prerequisite for admission to the exam.*			

Objectives

The students
- build on a solid basic education in physics to explore a field of research at the institutes of physics
- become familiar with the most important phenomena of magnetism
- learn about current research topics and typical applications of magnetic phenomena

Content

- Magnetization and susceptibility. Generation of magnetic fields
- Magnetism of atoms and ions. Curie and van Vleck paramagnetism. Crystal field.
- Magnetic interactions
- Magnetic models according to Heisenberg and Ising. Quantum effects and quantum states in magnetism.
- Magnetic order. Ferromagnets: Properties and applications. Antiferromagnets.
- Magnetic excitations. Magnonics.
- Magnetic crystallography, neutron scattering
- Exotic magnetic states: spin ice and magnetic monopoles; spin liquid; skyrmions.

References

- S. Blundell: "Magnetism in Condensed Matter"
- J. Stöhr, H.C. Siegmann: "Magnetism: From fundamentals to nanoscaledynamics"

Open Project Laboratory

Module type	Recommended for	Module availability	Module number and ECTS
elective	5^{th} semester	every winter semester	**12-PHY-BIOPL 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	

Responsibility
Director of the Peter Debye Institute for Soft Matter Physics / Director of the Felix Bloch Institute for Solid State Physics

Teaching units (SWS / tutorial hours / private study hours)
- Laboratory “Open Physics Laboratory” (4 SWS / 60 h / 90 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Project work (written report with preparation time 3 weeks, oral presentation of 30 min; ×1) *Pre-examination requirements: Written elaboration (project plan, 1 A4 page)*

Objectives

The aim of this module is to introduce students to the development of their own experimental and theoretical research ideas, to plan, implement and present them. After successful completion, students will be able to:

- work independently on a topic
- work out a reasonable time schedule for the project
- work problem-oriented in a team
- document their project and present it orally

Content

The project is worked on by the students in groups of two to four. After considering the experimental options in the Open Physics Lab, the students independently choose a topic from physics and suggest a methodology in a written elaboration (exposé, maximum one A4 page), with which they want to test the hypothesis developed from the topic. The exposés are reviewed by a committee consisting of the lab supervisors and two other university lecturers or scientific employees for feasibility and, if necessary, for referring back to the lab groups for revision.

The projects are accompanied by lab supervisors.

References

Recommendations for references and literature will follow in the course.

Stellar Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/8th semester	every summer semester	**12-PHY-BW3XAS1 5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	

Responsibility
Head of the department “Applied Quantum Systems” in cooperation with the Thuringian State Observatory Tautenburg
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Stellar Physics” (2 SWS / 30 h / 45 h) - Seminar “Stellar Physics” (2 SWS / 30 h / 45 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (25 min; ×1) *Pre-examination requirements: Presentation in the seminar (30 min)*

Objectives

The students
- acquire basic physical knowledge about the structure and development of stars
- learn about and assess modern astronomical observation methods
- open up themselves for a current field of research

Content

- observable physical properties of stars
- theory of stellar structure and evolution
- properties of stellar end stages
- scenario of the formation of stars and planetary systems
- extrasolar planets

References

- Francis LeBlanc, An Introduction to Stellar Astrophysics
- G.S. Bisnovatyi-Kogan, Fundamental Concepts and Stellar Equilibrium
- G.S. Bisnovatyi-Kogan, Stellar Evolution and Stability

Stellar Pysics Laboratory

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/8th semester	every summer semester	**12-PHY-BMWXAS2 5 CP**
Workload	Tutorial hours	Private study hours	
150 h	30 h	120 h	

Responsibility
Head of the department “Applied Quantum Systems” in cooperation with the Thuringian State Observatory Tautenburg
Teaching units (SWS / tutorial hours / private study hours)
- Laboratory “Stellar Physics Laboratory” (2 SWS / 30 h / 120 h)
Participation requirements
Participation in the module 12-PHY-BW3XAS1
Examinations (duration; weighting) and pre-examination requirements
Lab report (one report, preparation time 6 weeks; ×1)

Objectives

The students
- acquire the basic knowledge of modern observational techniques in the field of stellar spectroscopy
- learn how to prepare and perform observations
- learn how to evaluate stellar spectra.

Content

In the first part, students learn how to specify what should be observed, how it should be done, and what results are expected. In this part, students also learn how astronomical spectrographs and which detectors are used in optical astronomy and how they work. Students will learn how to use the telescope software.
In the second part the students perform measurements with the 2 m Alfred-Jensch- telescope (working place: observatory Tautenburg).
In the third part the students will learn how to evaluate Echelle spectra and which physical quantities of the stars can be derived from such spectra.

References

- Francis LeBlanc, An Introduction to Stellar Astrophysics
- Rirchard O. Gray und Christopher J. Corbally, Stellar Spectral Classification

Extragalactic Astronomy and Cosmology

Module type	Recommended for	Module availability	Module number and ECTS
elective	$5^{th}/7^{th}$ semester	every winter semester	**12-PHY-BMWXAS3** **5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	

Responsibility
Head of the department "Applied Quantum Systems" in cooperation with the Thuringian State Observatory Tautenburg
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Extragalactic Astronomy and Cosmology" (2 SWS / 30 h / 45 h) - Seminar "Extragalactic Astronomy and Cosmology" (2 SWS / 30 h / 45 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1) *Pre-examination requirements: Presentation in the seminar (30 min)*

Objectives

The students

- Have basic knowledge regarding the structure of galaxies, their manifestations and evolution, the large-scale structure in the universe, and know the formulation of cosmological world models and their verification by observations,
- know the basic physical relationships underlying these phenomena,
- know some modern astronomical observation methods and
- are able to access a current field of research.

Content

- structure of the Milky Way
- basic cosmological world models and their verification by observations
- structure, evolution and classification of galaxies, especially active galactic nuclei
- galaxy clusters and large-scale structure in the universe
- evidence for the presence of dark matter and dark energy
- important, current observational projects in various wavelength ranges

References

- P. Schneider, Extragalactic Astronomy and Cosmology, Springer 2015
- A. Liddle, An Introduction into Modern Cosmology, Wiley 2003

Extragalactic Astrophysics Laboratory

Module type	Recommended for	Module availability	Module number and ECTS
elective	$5^{th}/7^{th}$ semester	every summer semester	**12-PHY-BMWXAS4** **5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 90 h	

Responsibility
Head of the department “Applied Quantum Systems” in cooperation with the Thuringian State Observatory Tautenburg
Teaching units (SWS / tutorial hours / private study hours)
- Laboratory “Extragalactic Astronomy Laboratory” (2 SWS / 30 h / 120 h)
Participation requirements
Participation in the module 12-PHY-BMWXAS3
Examinations (duration; weighting) and pre-examination requirements
Lab report (one report, preparation time 6 weeks; ×1)

Objectives

The students
- know some modern observational methods of extragalactic astronomy,
- are proficient in various methods of displaying and analyzing observational data, especially in the radio, infrared, optical, and X-ray wavelengths,
- know statical methods for analyzing data and can quantify uncertainties in analysis results,
- know different resources especially of freely available data ("open data") for multi-wavelength analysis of extragalactic sources

Content

- observation methods of radio, infrared, optical astronomy and X-ray astronomy
- display of observations in the different wavelength ranges with e.g. ds9 and CASA
- creation of images, e.g. with Python/astropy
- determination of absolute magnitudes as well as their uncertainties
- working with larger ensembles
- interpretation of galaxy spectra, classification of galaxies
- analysis of single objects using multiwavelength observations

References

- Laboratory instructions

2.8 Physics Electives – Deepening the Specialization

Please note, that not all electives can be offered once a year. Check out the Course Catalogue for the list of modules being offered in the upcoming semester.

Superconductivity II

Module type elective	Recommended for 6^{th}/ 8^{th} semester	Module availability every summer semester	Module number and ECTS **12-PHY-MWPSUM2** **5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Head of the Department Superconductivity and Magnetism			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Superconductivity II” (2 SWS / 30 h / 45 h) - Laboratory “Superconductivity II” (2 SWS / 30 h / 45 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Oral exam (45 min; ×1) *Pre-examination requirements: Work on four experiments and elaborate lab reports (preparation 3 weeks). Points will be awarded for the evaluation of the reports. 75% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

The students
- will build on a solid background in physics to explore an area of research in the physics institutes
- will become familiar with the phenomena, theoretical concepts and microscopic theories of superconductivity
- will become familiar with typical applications of superconductivity
- will apply basic measurement methods in a professional manner
- will practice scientific presentations by presenting the results of an experiment

Content

Students get to know specialized subjects related to the dissipative processes in superconductors (Vortices and their movement), including the discussion of experimental results and recently published papers. Main concepts of the microscopic theory are also presented and discussed. The students have to dolaboratory work using usual research equipments like SQUID and AC magnetometry, Resistance and micro-Hall measurements, torque magnetometry, etc.

References

- D. R. Tilley and J. Tilley: Superfluidity and Superconductivity
- M. Tinkham: Introduction to Superconductivity
- R. P. Huebener: Magnetic Flux Structures in Superconductors
- P. G. de Gennes: Superconductivity of Metals and Alloys
- W. Buckel und R. Kleiner, Supraleitung

Superconductivity and Magnetism Laboratory

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPSUM3 5 CP**
Workload: 150 h	Tutorial hours: 105 h	Private study hours: 45 h	

Responsibility
Head of the Department Superconductivity and Magnetism
Teaching units (SWS / tutorial hours / private study hours)
- Laboratory “Superconductivity and Magnetism Laboratory” (7 SWS / 105 h / 45 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Lab report (one report, preparation time 3 weeks; ×1) *Pre-examination requirements: Presentation (45 min.)*

Objectives

The students get an overview of typical measurement methods of characterization of superconductors and magnetic materials and deepen their knowledge by applying selected methods of low temperature physics in the laboratory. They get in contact for the first time with the requirements of international research in the field of solid state physics.

Content

- Sample preparation, in part with the focused ion beam microscope.
- Characterization with electrical magnetoresistance methods, SQUID and AC susceptibility magnetometers, micro Hall sensors, capacitance measurements, and with microscopic methods such as magnetic force and atomic force microscopy, Andreev scattering, scanning tunneling microscopy

References

- Kittel: Introduction to Solid State Physics (Wiley) chapters on superconductivity and diamagnetism-paramagnetism-ferromagnetism

Magnetism

Module type elective	Recommended for 6th/7th/8th semester	Module availability irregular cycle	Module number and ECTS **12-PHY-MWPIOM6** **5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Head of the department “Applied Physics”			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “Magnetism” (2 SWS / 30 h / 45 h) - Seminar “Magnetism and Micromagnetic Modeling"” (2 SWS / 30 h / 45 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (90 min; ×1)			

Objectives

After active participation in the module, students will be able to qualitatively and quantitatively understand the physics of magnetism basing on the concepts of atomic and solid state physics. They will also learn about modern applications and current challenges in the field of magnetism from a from the physics fundamentals. They will also be introduced to modern methods, such as micromagnetic modeling. After active participation in the module, they will be able to work autonomously in the areas mentioned above.

Content

Lecture:

- Fundamentals: definitions, magnetism of free atoms.
- Heisenberg spin Hamiltonian operator, exchange interaction, Molecular field approximation
- Band magnetism, Stoner model
- Magnetism at surfaces and interfaces
- Dimensional effects
- Quantum well states, interlayer exchange coupling
- spin-dependent transport, GMR, TMR, spin valves, CMR
- Magnetic storage
- Exchange spring magnets, ferromagnetic shape memory alloys

Seminar:
Complementary to the lecture, talks on special topics in the field of micromagnetism (with a strong focus on magnetic domains) and its modeling will be given by the module participants.

References

- D.C. Jiles: Introduction to Magnetism and Magnetic Materials (Chapman & Hall, 1990)

X-Ray Techniques

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 8^{th} semester	irregular cycle	**12-PHY-MWPSEF1** **5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	
Responsibility Head of the Department of Structure and Properties of complex Materials			
Teaching units (SWS / tutorial hours / private study hours) - Lecture “X-Ray Techniques” (2 SWS / 30 h / 45 h) - Seminar “X-Ray Techniques” (1 SWS / 15 h / 60 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Oral presentation (20 min) and written report (preparation time 3 weeks); weighting ×1			

Objectives

Students will learn the basics of various X-ray based investigation methods, which are used for the analysis of the structure and composition of solids. By means of concrete examples, they will be able to analyze and evaluate the capabilities and limitations of the different methods. They will be to independently work on selected, advanced topics, to place them in the context of the lecture and to present them in a seminar talk.

Content

- X-ray sources: X-ray tubes, synchrotrons, other sources.
- X-ray diffraction and scattering techniques
- X-ray absorption-emission and fluorescence techniques
- X-ray imaging for the analysis of materials

References

- Als-Nielsen, Elements of Modern X-ray Physics, Wiley
- Zolotoyabko, Basic concepts of X-ray diffraction, Wiley
- Bokhoven/Lamberti, X-Ray Absorption and X-Ray Emission Spectroscopy, Wiley

Semiconductor Physics II: Semiconductor Devices II

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 8^{th} semester	every summer semester	**12-PHY-MWPHLP3 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the "Semiconductor Physics Group"			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Semiconductor Physics II: Semiconductor Devices II" (4 SWS / 60 h / 90 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (45 min; ×1)			

Objectives

The students

- build on a solid basic education in physics to further investigate in a research field of the physics institutes
- learn about the functionality, properties, and production of important semiconductor devices, in order to use this expertise to be able to further develop or design the corresponding components.

Content

The lecture will cover the physical fundamentals, properties, functionality and production of the most important modern semiconductor devices, e.g.:

- diodes
- transistors
- CMOS
- microelectronics
- photodetectors
- CCD's
- laser diodes
- optical communication systems
- solar cells

References

- M. Grundmann, The Physics of Semiconductors, Springer
- S. Sze, Physics of Semiconductor Devices, Wiley

Laboratory Work in Semiconductors II

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 8^{th} semester	every summer semester	**12-PHY-MWPHLP5** **5 CP**
Workload: 150 h	Tutorial hours: 30 h	Private study hours: 120 h	
Responsibility: Head of the “Semiconductor Physics Group”			
Teaching units (SWS / tutorial hours / private study hours): - Laboratory “Laboratory Work in Semiconductors II” (2 SWS / 30 h / 120 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Lab reports (8 experiments, 4 written reports (preparation time 4 weeks), 8 oral exams; ×1)			

Objectives

This lab course accompanies the module Semiconductor Physics II. Experiments are carried out on state-of-the-art equipment of the semiconductor physics group, which is also in daily use in current research projects.

The students
- acquire theoretical and experimental knowledge of basic fabrication and characterisation methods in modern semiconductor devices physics
- can independently apply and evaluate electronic and optical device properties;
- learn to familiarise themselves with problems in semiconductor technology, to solve them creatively and to present and defend the obtained results

Content

The students carry out 8 different experiments per semester according to a specified schedule. The lab course HLP II includes the complete fabrication of an oxide field-effect transistor in several processing steps as well as the Investigation of various other semiconductor devices such as diodes, light-emitting diodes, photodetectors, solar cells, and laser diodes.
The preparation for the experiments is done with the help of detailed scripts. The experiments are carried out under the guidance of a supervisor. The evaluation of the experiments is carried out by means of a report and an oral test or short presentation- each of which is graded.

References

- M. Grundmann: The Physics of Semiconductors, An Introduction including Devices and Nanophysics Springer, Heidelberg, 2006; Revised and extended 2nd edition 2009.

Semiconductor Physics III: Semiconductor Optics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPHLP6 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the “Semiconductor Physics Group”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture with integrated tutorial “Semiconductor Optics 1 - Fundamentals and Experimental Methods” (2 SWS / 30 h / 45 h) - Lecture with integrated tutorial “Semiconductor Optics 2 - Photonic Systems and Devices” (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Term paper (preparation time 6 weeks; ×1)			

Objectives

The students

- acquire basic knowledge in the field of crystal and semiconductor optics as well as selected aspects of the physics of light-matter interaction in modern semiconductor-based photonic systems
- acquire or deepen knowledge of specialized experimental methods in the field of optics
- learn to critically evaluate and understand recent publications in the field of optics, comprehend them and place them in their historical context.

Content

The following topics will be covered:

- Crystal and polarization optics (fundamentals and their practical application).
- Photons in confined photonic systems (resonators)
- elementary excitations in 3D-periodic structures
- weak and strong light-matter interaction
- experimental optical methods (e.g. Raman scattering, IR spectroscopy,ellipsometry, transmission and absorption spectroscopy)
- opto-electronic devices (e.g. photodiodes incl. solar cell, LED, laser etc.).

References

- C.F.Klingshirn: Semiconductor Optics; Springer, Berlin, 2007.
- P.Y.Yu and M.Cardona: Fundamentals of Semiconductors; Springer, Berlin, 1996.
- M. Born and E.Wolf: Principles of Optics; Cambridge University Press, Cambridge, 1999.
- M. Grundmann: The Physics of Semiconductors, An Introduction including Devices and Nanophysics Springer, Heidelberg, 2016 (3rd edition).

Magnetic Resonance and Imaging in Soft Matter

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 8th semester	every summer semester	**12-PHY-MWPAMR1** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department "Applied Magnetic Resonance"			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Magnetic Resonance and Imaging in Soft Matter" (2 SWS / 30 h / 45 h) - Exercise "Magnetic Resonance and Imaging in Soft Matter" (2 SWS / 30 h / 45 h)			
Participation requirements: Participation in the module 12-PHY-BW3MQ1 or similar knowledge recommended			
Examinations (duration; weighting) and pre-examination requirements: Portfolio (×1)			

Objectives

The students
- gain access to a current interdisciplinary field of magnetic resonance research
- acquire in-depth knowledge of nuclear magnetic relaxation processes
- acquire in-depth knowledge of diffusion measurements in soft matter systems with the aid of MR
- learn the basics of MR imaging
- deepen their knowledge by applying selected methods in exercises

Content

- Basics: intrinsic angular momentum in a magnetic field
- Relaxation in randomly fluctuating magnetic fields
- Bloch equations, BPP theory
- Relaxation mechanisms in soft matter
- Magnetic field gradients
- Diffusion as a relaxation mechanism
- Bloch-Torrey equations, q-space
- Fundamentals of transport measurements, pulse sequences
- Transport-structure correlations
- Selective pulses
- Image generation (MRT), k-space
- MRI pulse sequences
- MR contrasts
- Image generation in q-space

Notes on the module examination - the portfolio consists of
- three written tests (15 min. each) focusing on the topics of relaxation, diffusion and MRI
- two exercises connected with an experiment, including a short oral presentation of the results (up to 10 min)

References

- Callaghan, P. T., Translational Dynamics & Magnetic Resonance
- Haacke, M. E. et al., Magnetic Resonance Imaging: Physical Principles and Sequence Design
- Kimmich, R., NMR: Tomography, Diffusometry, Relaxometry

Nuclear Magnetic Resonance Laboratory

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	every semester	**12-PHY-MWPMQ3** **5 CP**
Workload: 150 h	Tutorial hours: 105 h	Private study hours: 45 h	
Responsibility: Head of the department “Magnetic Resonance of Complex Quantum Solids”			
Teaching units (SWS / tutorial hours / private study hours): - Laboratory “Nuclear Magnetic Resonance Laboratory” (7 SWS / 105 h / 45 h)			
Participation requirements: Participation in the modules 12-PHY-BW3MQ1 and 12-PHYMWPMQ2 or similar knowledge			
Examinations (duration; weighting) and pre-examination requirements: Written report (preparation time 4 weeks; ×1)			

Objectives

The students learn how to perform spin resonance experiments autonomously. They:

- by building on a solid background in physics, will develop a modern investigation methodology expertise, proper to the physics institutes
- will become familiar with the theoretical concepts of nuclear magnetic resonance (NMR) spectroscopy and will acquire experience in the application of NMR spectroscopy in the field of solid state physics and materials science
- deepen their practical skills through the application of selected NMR methods and setting up or building an NMR spectrometer

Content

- Fundamentals of high-frequency measurement techniques and signal processing in NMR spectroscopy
- Static and MAS NMR methods
- Echo methods
- Double resonance experiments
- Application of the acquired knowledge in the construction of a toy spectrometer

References

- Slichter: Principles of Magnetic Resonance (Springer)
- Levitt: Spin Dynamics (Wiley)

Electronic Spin Resonance Laboratory

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	every semester	**12-PHY-MWPMQ4 5 CP**
Workload 150 h	Tutorial hours 105 h	Private study hours 45 h	
Responsibility Head of the department "Magnetic Resonance of Complex Quantum Solids"			
Teaching units (SWS / tutorial hours / private study hours) - Laboratory "Electronic Spin Resonance Laboratory" (7 SWS / 105 h / 45 h)			
Participation requirements Participation in the modules 12-PHY-BW3MQ1 and 12-PHYMWPMQ2 or similar knowledge			
Examinations (duration; weighting) and pre-examination requirements Written report (preparation time 4 weeks; ×1)			

Objectives

The students get an overview of the measurement techniques of cw and pulsed electron paramagnetic resonance (EPR) spectroscopy and acquire knowledge about their application in the field of solid state physics and materials science. They deepen their practical knowledge by working on their own research project within the practical course.

Content

In the laboratory course, students are taught the quantum mechanical basics of cw EPR, its experimental techniques, and an overview of its various application fields (solid-state and semiconducting physics, materials science). Furthermore, the participants will familiarize themselves with a representative selection of momentum-EPR (ESEEM, HYSCORE) and double resonance experiments (ENDOR).

References

- Weil, Bolton: Electron Paramagnetic Resonance (Wiley)

Nuclear Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPKP1 5 CP**
Workload: 150 h	Tutorial hours: 45 h	Private study hours: 105 h	
Responsibility: Head of the "Structure and Properties of complex Materials Group"			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Nuclear Physics" (2 SWS / 30 h / 45 h) - Seminar "Nuclear Physics" (1 SWS / 15 h / 60 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Written exam (90 min; ×1) *Pre-examination requirements: Seminar presentation (15 min) on an experimental topic of nuclear physics (detectors, accelerators, applications) with subsequent discussion and preparation of the presentation slides.*			

Objectives

Students will acquire advanced knowledge of the fundamental properties of atomic nuclei and will become familiar with various models for describing them. They will be able to analyze and evaluate the achievements and limitations of these models. They will able to present an experimental aspect of nuclear physics (detector, accelerator, ...) in a short seinar talk. For that purpose, they will be able to acquire the necessary knowledge autonomously as well as to select the contents and to integrate them into the lecture material. They will discuss advantages and disadvantages of nuclear physics applications (nuclear reactors, medical applications).

Content

- Accelerators, interaction of particles with matter, detectors
- Mass, binding energy, radius, charge density distribution, spin, nuclear moments, parity
- Droplet model, Weizsäcker formula, Fermi gas model, shell model, rotation and vibration models
- Radioactivity, decay law, decay modes
- Nuclear fission, nuclear fusion, medical applications.

References

- Bethge/Walter/Wiedemann, Kernphysik, Springer
- Mayer-Kuckuk, Kernphysik, Teubner
- Musiol/Ranft/Reif/Seeliger, Kern- und Elementarteilchenphysik, VCH
- Krane, Introductory nuclear physics, Wiley
- Hodgson, Gadioli, Gadioli-Erba, Introductory nuclear physics, Clarendon Press

Particle Physics

Module type elective	Recommended for 7th semester	Module availability every winter semester	Module number and ECTS **12-PHY-MWPXT2** **5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	
Responsibility Director of the Felix Bloch Institute for Solid State Physics			
Teaching units (SWS / tutorial hours / private study hours) - Lecture "Particle Physics" (2 SWS / 30 h / 45 h) - Exercise "Particle Physics" (1 SWS / 15 h / 60 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (120 min; ×1) *Pre-examination requirements: Solution of weekly exercises on the module content, for which points will be awarded. Prerequisite for admission to the exam is the achievement of 50% of the possible points of the semester.*			

Objectives

The students
- will become familiar with the concepts and the standard model of modern particle physics
- will be introduced to unifying theories and the origin of the universe

Content

- The Quark Model and the Building Blocks of the World
- Symmetries and conservation laws
- Phenomenology of the weak interaction: Neutrino physics, parity violation, CP violation.
- Gauge theories and the standard model of particle physics: the electroweak theory, quantum chromodynamics and the strong interaction
- Grand unified theories: Proton decay, neutrino oscillations
- Measurement methods and detectors of particle physics

References

- Ch. Berger, Elementarteilchenphysik, Springer, 2006.
- M. Thomson, Modern Particle Physics, Cambridge University Press, 2018.
- D. Griffiths, Introduction to Elementary Particles, Wiley-VCH, 2008.

Quantum Technology 2

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 8th semester	every summer semester	**12-PHY-MWPQT2** **5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	

Responsibility
Head of the department “Applied Quantum Systems”
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Quantum Technology 2” (2 SWS / 30 h / 45 h) - Seminar “Quantum Technology 2” (1 SWS / 15 h / 60 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (120 min; ×1)

Objectives

After successful participation in the course, students will be able to

- by building on a solid basic education in physics, autonomously research a current application of quantum optics in science and technology and present it in the form of a seminar talk
- explain and evaluate methods and challenges of quantum optics
- apply the acquired knowledge to hypothetical practical scenarios

Content

The lecture gives an introduction to quantum optics in the topic areas:

- Atom-light WW
- lasers
- photostatistics
- antibunching
- Fockstate
- Coherentstate
- squeezed light
- atom in cavities
- entangled states
- quantum cryptography

References

- Introduction to Quantum optics: G. Grynberg, A. Aspect and C Fabre, ISBN978-0-521-55112-0
- Quantum Optics: M.O. Scully and M.S.Zubairy 2008, ISBN978-0-521-43595-6

Quantum Technology 3

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPQT3** **5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	

Responsibility
Head of the department “Applied Quantum Systems”
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Quantum Technology 3” (2 SWS / 30 h / 45 h) - Seminar “Quantum Technology 3” (1 SWS / 15 h / 60 h)
Participation requirements
None. Participation in module 12-PHY-MWPQT2 is recommended
Examinations (duration; weighting) and pre-examination requirements
Written exam (120 min; ×1)

Objectives

After successful participation in the course, students will be able to

- by building on a solid basic education in physics, autonomously research a current application of quantum technology in science and technology and present it in the form of a seminar talk
- explain and evaluate methods and challenges of quantum technology
- apply the acquired knowledge to hypothetical practical scenarios.

Content

The lecture gives an introduction to quantum technology, quantum computing and quantum sensors.

Topic areas:

- what are qubits?
- basics of a computer
- quantum computer
- quantum error correction
- adiabatic QC (D-WAVE)
- quantum sensors
- practical realization

References

- Quantum Computation and Quantum Information: M.A. Nielsen and I.L.Chung. ISBN 978-1-1-107-00217-3

Active Matter Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 8th semester	every summer semester	**12-PHY-MWPMON3 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the department “Molecular Nanophotonics”			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Active Matter Physics” (2 SWS / 30 h / 45 h) - Seminar “Active Matter Physics” (1 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (30 min; ×1)			

Objectives

Students will learn the diverse phenomena of active matter and the underlying concepts using examples from biological and non-biological systems. They will develop theoretical skills for the description of active matter, as well as procedures for the production, analysis and control of active matter in experiments. Students will be able to critically discuss current research results and work independently on small projects.

Content

Active matter consists of units that convert energy into motion, violating numerous fundamental symmetries of non-living matter (e.g., reciprocity of interactions, conservation of energy, etc.).
Contents of the module include:

- physical description of active matter: microscopically and field theoretically as many-particle systems and phenomenologically, thermodynamically and hydrodynamically, via its symmetries and symmetry breaking, respectively
- an overview of active biological materials, such as molecular motors, cilia, flagella, bacteria, etc. and associated phenomena and, for example, ways to control them
- An overview of synthetic active materials, drive mechanisms (e.g., phoretic), their production, analysis, and control
- active matter in external fields (e.g., chemotaxis, gravitaxis, ...)
- collective behavior of active matter (e.g. swarms)

References

- M. C. Marchetti, J. F. Joanny, S. Ramaswamy, T. B. Liverpool, J. Prost, M. Rao, and R. A. Simha, "Hydrodynamics of soft active matter", Reviews Modern Physics 85, 1143 (2013).
- S. Ramaswamy, "The mechanics and statistics of active matter", AnnualReviews Condensed Matter Physics 1, 323 (2010).
- C. Bechinger, R. Di Leonardo, H. Löwen, C. Reichhardt, G. Volpe, and G. Volpe, "Active particles in complex and crowded environments", Reviews Modern Physics 88, 045006 (2016).
- F. Cichos, K. Gustavsson, B. Mehlig, and G. Volpe, "Machine learning for active matter", Nature Machine Intelligence 2, 94 (2020).
- G. Baffou, F. Cichos, and R. Quidant, "Applications and challenges of thermoplasmonics", Nature Materials (2020).
- M. R. Shaebani, A. Wysocki, R. G. Winkler, G. Gompper, and H. Rieger, "Computational models for active matter", Nature Reviews Physics 2, 181 (2020).
- G. Volpe, F. Cichos, and C. Bechinger, "Taking control of active matter", (2020).
- Literature from the seminar

Physics of Nanoporous Materials

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	irregular cycle	**12-PHY-MWPGFP 5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	

Responsibility
Head of the Department of Applied Magnetic Resonance

Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Physics of Nanoporous Materials" (2 SWS / 30 h / 45 h) - Seminar "Physics of Nanoporous Materials" (1 SWS / 15 h / 25 h) - Laboratory "Physics of Nanoporous Materials" (1 SWS / 15 h / 10 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Oral exam (25 min; ×1) *Pre-examination requirements: Lab report (one report, preparation time 3 weeks)*

Objectives

The students
- acquire the basics of a current interdisciplinary research field of nanotechnology
- acquire comprehensive knowledge of the characterization of nanoporous materials
- learn experimental and theoretical methods for the description and investigation of phase equilibria and phase transitions and for transport processes of porous elements in confining geometries
- deepen their knowledge by applying selected methods in the laboratory

Content

The module provides knowledge of general molecular and solid state physics. Phenomenological descriptions and applications of natural and synthetic porous solids using macroscopic and microscopic structural parameters are covered. The geometric structure and internal structure of nanoporous materials, principles for the synthesis of dispersed and porous solids, and modern experimental methods and theories for the study of structure, adsorption, and diffusion in porous materials will be discussed and illustrated with examples from current research. Diffusion studies using, for example, interference and IR microscopy, PFG NMR, and the energy and structure characterization of porous solids using adsorption texture analysis, calorimetry, and MAS NMR will be explained.
In the seminar and laboratory, students deepen the knowledge learnt in the lectures.

References

Recommendations for references and literature will follow in the course.

Single-Molecule Spectroscopy

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPEMSP 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	

Responsibility
Head of the Department of Molecular Biophysics
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Single-Molecule Spectroscopy" (2 SWS / 30 h / 45 h) - Laboratory "Single-Molecule Spectroscopy" (2 SWS / 30 h / 45 h)
Participation requirements
None. The modules 12-PHY-BIEP5 as well as 12-PHY-MWPMON3 are a good complement to this course.
Examinations (duration; weighting) and pre-examination requirements
Oral exam (30 min; ×1) *Pre-examination requirements: Lab report (3 reports, preparation time 4 weeks)*

Objectives

Students will acquire an understanding of fundamental physical techniques and the knowledge used in the study and characterization of single biological and non-biological molecules as constituents of soft condensed matter. Students will get a detailed insight into this subject area and will be able to perform single molecule experiments autonomously and analyze them by means of computer-aided calculations. The students deepen their understanding of the structure and dynamics of soft and biological systems.

Content

Lecture:
Biological and soft matter systems can exhibit complex behavior in terms of their structure and dynamics. This is usually the result of a collective interaction between the individual passive or active molecules of which these systems are composed. To understand the macroscopic properties, it is essential to know the molecular properties of the systems. The aim of thecourse is to get to know mechanical and optical single molecule methods, with which the structure and dynamics of single molecules can be analyzed and followed in real time. This allows e.g. insight into subpopulations of molecules and states, the investigation of active, i.e. force generating molecules as well as microscopy beyond Abbe's diffraction limit. Specific lecture topics include:

- Structure and dynamics of biomolecules
- Methods of force spectroscopy (tweezer techniques, AFM)
- Theoretical descriptions of force spectroscopic experiments
- Fluorescence spectroscopy (fluorescence lifetime, fluorescence anisotropy)
- Multidimensional fluorescence spectroscopy
- Quantitative evaluation of fluorescence experiments with applications to thestructure of macromolecules
- Fundamentals of signal and data analysis in spatial and frequency space, statistical analysis of data with limited statistics

Laboratory:
Realization and analysis of single-molecule experiments. Presentation of the results obtained in a report.

References

- Jonathan Howard: Mechanics of Motor proteins and the Cytoskeleton (Sinauer Associates)
- Rob Pillips, Jane Kondev, Julie Theriot: Physical Biology of the Cell (Garland Science)
- Joseph R. Lakowicz: Principles of Fluorescence Spectroscopy (Springer)

Cellular Biophysics

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPM1 5 CP**
Workload 150 h	Tutorial hours 60 h	Private study hours 90 h	
Responsibility Head of the Department of Biological Physics			
Teaching units (SWS / tutorial hours / private study hours) - Lecture "Cellular Biophysics" (2 SWS / 30 h / 45 h) - Seminar "Cellular Biophysics" (2 SWS / 30 h / 45 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Portfolio (×1)			

Objectives

The students
- based on a solid fundamental physics education, will develop a field of actual research in the institutes of physics
- will acquire basic knowledge of physical properties of cells and physical processes involved in fundamental biological processes
- will access to current developments in the field of cellular biophysics

Content

The module builds on the training in Experimental and Theoretical Physics in the Bachelor's program.

Lecture "Cellular Biophysics": Basic physical properties of functional modules important for biological cells are covered. Principal contents of the lecture:
- Structure of the cell
- Cell components: Cell membrane, cell organelles, cytoskeleton
- Cell division and cell cycle
- Transcription (DNA) and translation (proteins): Organization of the genome
- Cell surface receptors: cell-matrix and cell-cell adhesion
- Macromolecules of the extracellular matrix
- Micromechanics of the cell
- Endothelial cell mechanics

Seminar "Cellular Biophysics: Recent fundamental work in the field of cellular biophysics will be studied in individual presentations and by assignments.

Note on the examination: The composition of the portfolio will be announced by the lecturers at the beginning of the module. Examples of contributions to the portfolio are: Presentations, papers, contributions to discussions and written tests. The processing time for the compilation of the portfolio after the provision of all the material is four weeks.

References

- Claudia Tanja Mierke, Cellular Mechanics and Biophysics, Structure and Function of Basic Cellular Components Regulating Cell Mechanics, eBook ISBN: 978-3-030-58532-7
- Erich Sackmann und Rudolf Merkel, Lehrbuch der Biophysik, Wiley-VCH, ISBN978-3-527 40535-0

Experimental Methods in Biophysics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 8th semester	every winter semester	**12-PHY-MWPM3** **5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the Department of Biological Physics			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Experimental Methods in Biophysics” (2 SWS / 30 h / 45 h) - Seminar “Experimental Methods in Biophysics” (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Portfolio (×1)			

Objectives

The students
- based on a solid fundamental physics education, will develop a field of actual research in the institutes of physics
- will acquire basic knowledge of methods for measuring physical properties of cells, physical measurement techniques for characterizing biological samples, and physical properties of important classes of molecules,
- access current developments in the field of biophysics and physical disease research

Content

The module builds on the training in Experimental and Theoretical Physics in the Bachelor's program in Physics and "International Physics Studies Program", respectively.
Lecture: The basic physical measurement techniques for the investigation of biological samples such as optical microscopy, spectroscopy and scattering techniques will be studied.
Seminar: Recent fundamental work in the field of Biophysical methods will be worked out by the participants in individual presentations and by tasks.

Note on the examination: The composition of the portfolio will be announced by the lecturers at the beginning of the module. Examples of contributions to the portfolio are: Presentations, papers, contributions to discussions and written tests.The processing time for the compilation of the portfolio after the provision of all the material is four weeks.

References

- Patrick F. Dillon, Biophysics, A Physiological Approach, Cambridge University Press, ISBN 978-0-521-172165
- Erich Sackmann und Rudolf Merkel, Lehrbuch der Biophysik, Wiley-VCH, ISB 978-3-527-40535-0

Physics of Cancer I

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPPOC1 5 CP**
Workload: 150 h	Tutorial hours: 60 h	Private study hours: 90 h	
Responsibility: Head of the Department of Biological Physics			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Physics of Cancer I” (2 SWS / 30 h / 45 h) - Seminar “Physics of Cancer I” (2 SWS / 30 h / 45 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Portfolio (×1)			

Objectives

The students
- will be introduced to an interdisciplinary area of physics, biochemistry and medicine
- will gain basic knowledge about mechanical properties of cancer cells and cancer cell clusters, and of physical processes involved in the development of tumors and their malignant spreading
- gain an understanding of current developments in the field of tumor physics

Content

Lecture Physics of Cancer I: Basic physical properties of tumor cells will be covered, which are of great importance for the spread of the disease:
- Origin of tumors
- Benign or malignant tumor and metastasis
- Characteristics of cancer
- Cell culture technique of cancer cells
- Influence of cell culture on tumor cell mechanics
- Motility assays in 2D and 3D and biochemical and physical Migration models
- Interaction of tumor cells with their environment and influence of environmental mechanics
- Inflammation and tumors: influence on the mechanical properties of tumor cells
- Tumor spheroids and measurement of their mechanical properties
- Analysis of mechanical properties of tumor resection

Seminar Physics of Cancer I: The seminar will cover basic concepts, experimental methods and recent scientific publications on the above topics. Participants will present in a seminar talk topics on a given fundamental paper/book or concept in the field of Physics of Cancer individually or in group and answer questions in the discussion of the presentation.

Note on the examination: The composition of the portfolio will be announced by the lecturers at the beginning of the module. Examples of contributions to the portfolio are: Presentations, papers, contributions to discussions and written tests.The processing time for the compilation of the portfolio after the provision of all the material is four weeks.

References

- Claudia Tanja Mierke, Physics of Cancer Volume 1, IOP Publishing, Online ISBN:978-0-7503-1753-5 and Print ISBN: 978-0-7503-1751-1
- Claudia Tanja Mierke, Physics of Cancer Volume 2, IOP Publishing, Online ISBN: 978-0-7503-2117-4 and Print ISBN: 978-0-7503-2114-3

Physics of Cancer II

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 8^{th} semester	every summer semester	**12-PHY-MWPPOC2 5 CP**
Workload 150 h	Tutorial hours 45 h	Private study hours 105 h	
Responsibility Head of the Department of Biological Physics			
Teaching units (SWS / tutorial hours / private study hours) - Lecture "Physics of Cancer II" (2 SWS / 30 h / 45 h) - Seminar "Physics of Cancer II" (2 SWS / 30 h / 45 h)			
Participation requirements Participation in the module 12-PHY-MWPPOC1 recommended			
Examinations (duration; weighting) and pre-examination requirements Portfolio (×1)			

Objectives

The students
- receive advanced training in an interdisciplinary area of physics, biochemistry, and medicine,
- will gain basic knowledge of mechanical properties of cancer cells and interacting cells, as well as physical processes involved in fundamental biological processes of the tumor
- gain insight into current developments in the field of tumor physics

Content

Lecture Physics of Cancer II: Basic physical properties of tumor cells will be covered, which are of great importance for the progression of the disease:
- Introduction to physical tumor research
- Explanation of different physical approaches to the development of of tumors
- Model systems to study the physical properties of tumor cells
- Interaction of tumor cells and endothelial cells and their mutual influence on the mechanical properties
- Development of tumor endothelial cells and their characterization
- Combination of cell biological techniques with physical techniques
- Selection of malignant and highly invasive tumor cells
- Influence of gene expression on cell mechanics
- Structure, architecture and mechanics of tumor cell nuclei
- Theoretical models of tumorigenesis

Seminar Physics of Cancer II: The seminar will cover recent fundamental work in the field of tumor physics. Participants will present topics in seminar talks individually or in groups and answer questions in the discussion of the presentation.

Note on the examination: The composition of the portfolio will be announced by the lecturers at the beginning of the module. Examples of contributions to the portfolio are: Presentations, papers, contributions to discussions and written tests.The processing time for the compilation of the portfolio after the provision of all the material is four weeks.

References

- Claudia Tanja Mierke, Physics of Cancer Volume 1, IOP Publishing, Online ISBN:978-0-7503-1753-5 and Print ISBN: 978-0-7503-1751-1
- Claudia Tanja Mierke, Physics of Cancer Volume 2, IOP Publishing, Online ISBN: 978-0-7503-2117-4 and Print ISBN: 978-0-7503-2114-3

Stochastic Processes in Physics, Biology and Earth Sciences

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	every two years	**12-PHY-MWPTKS1** **10 CP**
Workload: 300 h	Tutorial hours: 90 h	Private study hours: 210 h	
Responsibility: Head of the Department of Complex Systems			
Teaching units (SWS / tutorial hours / private study hours): - Lecture “Stochastic Processes in Physics, Biology and Earth Sciences” (4 SWS / 60 h / 80 h) - Exercise “Stochastic Processes in Physics, Biology and Earth Sciences” (2 SWS / 30 h / 130 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (45 min; ×1)			

Objectives

The lecture is intended to give an introduction to the fundamentals of the theory of stochastic processes from the point of view of physics and to facilitate independent study of further literature and original papers. This should improve the understanding of stochastic phenomena from physics and other disciplines. The methods will be introduced and motivated in view of concrete applications.

Content

- Characterization of random variables and stochastic processes (limit theorems, large deviations), applications in statistical physics.
- Markov processes (Chapman-Kolmogorov equation, master equation, Kramer- Moyal evolution, Fokker-Planck equation), application to diffusion processes, granular gases and ASEPs, fluctuation relations according to Lebowitz and Spohn
- Continuous stochastic processes (Gaussian processes, Ornstein-Uhlenbeck process, white noise, Wiener process), discussion of Brownian motion and normal diffusion
- Lévy processes (stable probability distributions), causes of anomalous diffusion
- Langevin and Fokker-Planck equations (stochastic differential equations and stochastic integrals, Ito vs. Stratonovich), applications to transport Transport Theory and Stochastic Thermodynamics: fluctuation theorems, Jarzynski equation, Crook's fluctuation theorem.

Note on the exam: The oral exam consists of a presentation (30 min.) with discussion (15 min.).

References

- H. Haken: Synergetics. An Introduction (Springer, 1983)
- C.W. Gardiner; Handbook of Stochastic Methods (Springer, 1985)
- Current contributions from summer schools and professional journals

Non-linear Dynamics and Pattern Formation

Module type	Recommended for	Module availability	Module number and ECTS
elective	1st semester	every two years	**12-PHY-MWPTKS2 10 CP**
Workload: 300 h	Tutorial hours: 90 h	Private study hours: 210 h	
Responsibility: Head of the Department of Complex Systems			
Teaching units (SWS / tutorial hours / private study hours): - Lecture "Non-linear Dynamics and Pattern Formation" (4 SWS / 60 h / 80 h) - Exercise "Non-linear Dynamics and Pattern Formation" (2 SWS / 30 h / 130 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Oral exam (45 min; ×1)			

Objectives

The lecture is intended to give an introduction to the basic concepts of the theory of theory of nonlinear dynamical systems and structure formation and to provide the basics to study further literature and original papers autonomously and to provide at least a qualitative understanding of a variety of nonlinear phenomena in physics and other disciplines.
First, systems with few degrees of freedom will be discussed. Then, methods for the description of systems with (infinitely) many degrees of freedom are presented, in particular of spatially extended systems and of systems with temporal temporal delay.
Experimental applications are discussed for all the concepts introduced and - as far as possible - also presented in the lecture. The students will learn to measure data from their own experiments, to carry out numerical analyses of the corresponding experiments and to evaluate their data.

Content

- Dynamical systems with few degrees of freedom (characterization of flows, classification of singular points, periodic solutions, bifurcations, normal forms, central manifolds, structural stability, catastrophes, chaos in Hamiltonian and dissipative systems).
- Pattern formation in driven systems (multiscale analysis, amplitude equation for Rayleigh-Benard instability, phenomenological amplitude equations, Eckhaus and Benjamin-Feir instabilities, reaction-diffusion systems, Turing instabilities).
- More advanced topics will be discussed in agreement with the students.

References

- G. Nicolis: Introduction to Nonlinear Science (Cambridge UP, 1995)
- E. Ott: Chaos in Dynamical Systems (Cambridge UP, 2002)
- M. Cross, H. Greenside: Pattern Formation and Dynamics (Cambridge UP, 2009)

Practical Course: Complex Systems

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 7th/ 8th semester	every semester	**12-PHY-MWPTKS3 5 CP**
Workload: 150 h	Tutorial hours: 30 h	Private study hours: 120 h	
Responsibility: Head of the Department of Condensed Matter Theory			
Teaching units (SWS / tutorial hours / private study hours): - Laboratory "Practical Course: Complex Systems" (2 SWS / 30 h / 120 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Project work (written report with preparation time 4 weeks, oral presentation of 45 min; ×1)			

Objectives

In parallel to the modules 12-PHY-MWPTKS1 or 12-PHY-MWPTKS2, autonomous theoretical work (practicing analytical and numerical techniques, literature research, model building, problem solving, etc.) on some actual research project will be practiced under supervision. The results will be discussed in the working group and presented both in oral and written form.

Content

The contents of the module are adapted to the interests and the level of knowledge of the students. The following topics are available for selection: phase transitions far from equilibrium, anomalous transport, tipping points and instabilities in biological systems or in climate models.

References

Recommendations for references and literature will follow in the course.

Theory of Soft and Bio Matter

<table>
<tr><td>Module type
elective</td><td>Recommended for
6th/ 7th/ 8th semester</td><td>Module availability
Irregular cycle</td><td rowspan="2">Module number and ECTS
12-PHY-MWPTKM3
10 CP</td></tr>
<tr><td>Workload
300 h</td><td>Tutorial hours
90 h</td><td>Private study hours
210 h</td></tr>
<tr><td colspan="4">Responsibility
Head of the Department of Condensed Matter Theory</td></tr>
<tr><td colspan="4">Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Theory of Soft and Bio Matter” (4 SWS / 60 h / 80 h)
- Exercise “Theory of Soft and Bio Matter” (2 SWS / 30 h / 130 h)</td></tr>
<tr><td colspan="4">Participation requirements
Students are recommended to have a basic knowledge of Thermodynamics and Statistical Mechanics</td></tr>
<tr><td colspan="4">Examinations (duration; weighting) and pre-examination requirements
Written exam (120 min; ×1)

Pre-examination requirements: Regularly handed out exercises with tasks related to the module content. Points are awarded for solutions. Prerequisite for admission is the achievement of 50% of the possible points of the entire semester.</td></tr>
</table>

Objectives

Students will learn fundamental phenomena, concepts and methods of soft condensed matter theory and their importance for the quantitative description of biological matter. In addition, the interdisciplinary application of methods of theoretical physics will be practiced in general.

Content

Essential contents are:

- Concepts from statistical physics and thermodynamics for many-particle systems, fluctuations and response.
- Density functional theories, field theories, functional integrals
- Perturbative and non-perturbative methods
- Model systems (e.g. colloids, polymers, membranes, granular matter)
- Biological systems (e.g., cell/tissue structure and mechanics).

The courses are taught in English. Study and exams have to be taken in English.

References

- P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics, Cambridge 1995
- P.-G. de Gennes, Scaling Concepts in Polymer Physics, Cornell 1979
- M. E. Cates, M. R. Evans, Soft and Fragile Matter: Nonequilibrium Dynamics, Metastability and Flow, IOP 2000

Practical Course: Condensed Matter Theory

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	every semester	**12-PHY-MWPTKM4 5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 120 h	
Responsibility Head of the Department of Condensed Matter Theory			
Teaching units (SWS / tutorial hours / private study hours) - Practice "Practical Course: Complex Systems" (2 SWS / 30 h / 120 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Project work (written report with preparation time 4 weeks, oral presentation of 45 min; ×1)			

Objectives

After active participation in the module, students will be able to:
- familiarize themselves with conceptual and methodological techniques of condensed matter theory
- understand basic notions of literature research
- work on and solve simple model problems autonomously, and justify their approach

Content

The contents of the module are adapted to the interests and the level of knowledge of the students. For example, the following topics are available for the student to choose among:
- soft matter
- biological physics
- stochastic dynamics
- statistical physics of non-equilibrium
- networks

The course is taught in English. Study and examinations must be taken in English.

References

Original literature depending on the topic.

General Relativity

Module type	Recommended for	Module availability	Module number and ECTS
elective	7th semester	every winter semester	**12-PHY-MWPQFG1 10 CP**
Workload: 300 h	Tutorial hours: 90 h	Private study hours: 210 h	

Responsibility
Head of the Department of Quantum Field Theory and Gravitation, Head of the Department of Elementary Particle Theory

Teaching units (SWS / tutorial hours / private study hours)
- Lecture “General Relativity” (4 SWS / 60 h / 80 h)
- Exercise “General Relativity” (2 SWS / 30 h / 130 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1)

Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.

Objectives

After active participation in the module, students will be able to:
- present and explain the basic terms, concepts and methods of general relativity orally and in written form
- apply them to investigate and predict the behavior of simple general relativistic systems
- work through and solve simple model problems autonomously and justify their approach

Content

- Terms from special relativity, mass-energy equivalence
- Basics of differential geometry: manifolds, tangent bundles, tensor fields, metrics and relations, geodesics, Riemannian curvature tensor, Jacobian equation, isometries, foliations
- Einstein field equation and its interpretation, special solutions: Friedmann-Robertson-Walker cosmological models, cosmic expansion, Schwarzschild outer and inner space solution
- Stability of stellar matter, Oppenheimer-Tolman-Volkhoff limit, Harisson-Wheeler diagrams, Chandrasekar limit, gravitational collapse to black hole
- Spacetime structure of black holes, singularities, horizons, cosmic censorship, singularity theorems

References

- R.M. Wald: General Relativity, University of Chicago Press, 1984
- S.M. Caroll: Spacetime and Geometry, Addison-Wesley 2003
- J.B. Hartle: Gravity: An Introduction to Einstein's General Relativity, Cummings 2002
- N. Straumann, General Relativity, Springer 2013

Cosmology

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 7th/ 8th semester	irregular cycle	**12-PHY-MWPQFG2 10 CP**
Workload: 300 h	Tutorial hours: 90 h	Private study hours: 210 h	

Responsibility
Head of the Department of Quantum Field Theory and Gravitation

Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Cosmology” (4 SWS / 60 h / 80 h) - Exercise “Cosmology” (2 SWS / 30 h / 130 h)

Participation requirements
None

Examinations (duration; weighting) and pre-examination requirements
Oral exam (45 min; ×1)

Objectives

After active participation in the module, students will be able to:
- present and explain orally and in written form the basic terms, concepts, methods, and results of modern cosmology
- apply these methods autonomously to study the behavior of simple cosmological models and justify their approach

Content

- Historical overview: evolution of cosmology
- Observability and results, distance scales, matter counting, motion of galaxies and galaxy clusters
- brief overview of general relativity, cosmological spacetime models, cosmic expansion in theory and comparison with observational results
- Thermal behavior of radiation and matter in the early universe, baryogenesis, nucleosynthesis, recombination; helium excess, background radiation temperature
- Horizon problem, inflationary scenarios
- Dark Matter
- Fluctuations of geometry in the early universe as the seeds of structure formation, quantization

References

- H. Goenner: Kosmologie, Spektrum, 1998
- S. Weinberg: Cosmology, Oxford University Press, 2008
- S. Dodelson: Modern Cosmology, Academic Press, 2003

Quantum Field Theory on Curved Space Times

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	irregular cycle	**12-PHY-MWPQFG3 10 CP**
Workload 300 h	Tutorial hours 90 h	Private study hours 210 h	

Responsibility
Head of the Department of Quantum Field Theory and Gravitation
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Quantum Field Theory on Curved Space Times” (4 SWS / 60 h / 80 h) - Exercise “Quantum Field Theory on Curved Space Times” (2 SWS / 30 h / 130 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Oral exam (45 min; ×1)

Objectives

After active participation in the module, students will be able to:

- present and explain both orally and in writing form the basic terms, concepts, and methods of quantum field theory on curved spacetimes
- apply them to study and predict the behavior of simple field-theoretical systems
- work on and solve simple model problems autonomously and justify their approach

Content

- Quantization of linear field theories in Minkowski space
- Globally hyperbolic spacetimes, quantization of linear fields on globally hyperbolic spacetimes, Hadamard states
- General covariant quantum field theory: foundations, structural statements
- Particle generation in external gravitational fields for linear quantum fields
- Hawking effect
- Particle generation in the early universe
- The renormalized energy-momentum tensor
- Outlook: Perturbative quantization/renormalization program for interacting quantum fields

References

- R.M. Wald: General Relativity, University of Chicago Press, 1984
- R.M. Wald: Quantum Field Theory in Curved Spacetime and Black Hole
- Thermodynamics, University of Chicago Press, 1996
- R. Haag: Local Quantum Physics, Springer, 2nd ed., 1996
- S. Fulling: Aspects of Quantum Field Theory in Curved Spacetime, CUP, 1990
- N.D. Birrell, P.C.W. Davies: Quantum fields in curved space, CUP 1984

Practical Course: Quantum Field Theory and Gravity

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 7th/ 8th semester	every semester	**12-PHY-MWPQFG6** **5 CP**
Workload 150 h	Tutorial hours 30 h	Private study hours 120 h	
Responsibility Head of the Department of Quantum Field Theory and Gravitation			
Teaching units (SWS / tutorial hours / private study hours) - Practice "Practical Course: Quantum Field Theory and Gravity" (2 SWS / 30 h / 120 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Project work (written report with preparation time 4 weeks, oral presentation of 45 min; ×1)			

Objectives

After active participation in the module, students will be able to:

- familiarize themselves with conceptual and methodological techniques of quantum field theory and gravitation
- understand basic notions of literature research
- work on and solve simple model problems autonomously, and justify their approach

Content

The contents of the module are adapted to the interests and the level of knowledge of the students. For example, the following topics are available for the student to choose among:
Gauge field theory, differential geometric aspects of theoretical physics, gravitational theory, quantum field theory, non-commutative geometry, quantum information theory.

The course is taught in English. Study and examinations must be taken in English.

References

References to literature will be given in the course

Relativistic Quantum Field Theory

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 7th/ 8th semester	irregular cycle	**12-PHY-MWPTET4 10 CP**
Workload 300 h	Tutorial hours 90 h	Private study hours 210 h	
Responsibility Head of the Department of Elementary Particle Theory			
Teaching units (SWS / tutorial hours / private study hours) - Lecture "Relativistic Quantum Field Theory" (4 SWS / 60 h / 80 h) - Exercise "Relativistic Quantum Field Theory" (2 SWS / 30 h / 130 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

After active participation in the module, students will be able to:

- present and explain both orally and in writing form the basic terms, concepts, and methods of relativistic quantum field theory
- apply them to study and predict the behavior of simple field-theoretical systems
- work on and solve simple model problems autonomously and justify their approach

Content

- Free quantized field theories
- Fock space, representations of the Poincaré group
- Scattering matrix, Feynman rules
- Perturbative evolution, principles of renormalization theory
- Gauge field theories

References

- M. Srednicki, Quantum Field Theory, Cambridge University Press (2007)
- C. Itzykson, J.B. Zuber, Quantum Field Theory, Dover Books on Physics (2006)
- S. Weinberg, The Quantum Theory of Fields, Cambridge University Press (1995)
- J. Zinn-Justin, Quantum field theory and critical phenomena, Oxford University Press, (1996)

Quantum Field Theory of Many-Particle Systems

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	irregular cycle	**12-PHY-MWPSTP1 10 CP**
Workload 300 h	Tutorial hours 90 h	Private study hours 210 h	

Responsibility
Head of the Department of Statistical Physics
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Quantum Field Theory of Many-Particle Systems" (4 SWS / 60 h / 140 h) - Exercise "Quantum Field Theory of Many-Particle Systems" (2 SWS / 30 h / 70 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students will learn both fundamental concepts and methods of quantum field theory as well as important examples of its application. On the basis of functional integrals, knowledge is acquired through the study of applications in the fields of nanophysics, unordered systems, and strongly correlated systems. The students will be able to work on current problems in the field of many-body physics using methods of quantum field theory.

Content

- Functional integrals of many particle systems
- Green's functions, response functions and observables
- Perturbation theory and mean field approximation
- Collective quantum fields and fluctuations
- Renormalization group
- Dissipative quantum tunneling
- Topological field theory

References

- A. Altland and B.D. Simons, Condensed Matter Field Theory (Cambridge University Press)
- X.-G. Wen, Quantum Field Theory of Many-Body Systems: From the Origin of Sound to an Origin of Light and Electrons (Oxford Graduate Texts)
- H. Orland and J.W. Negele Quantum Many Particle Systems, Addison-Wesley

Statistical Mechanics of Deep Learning

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 7th/ 8th semester	every winter semester	**12-PHY-MWPSTP2 10 CP**
Workload: 300 h	Tutorial hours: 90 h	Private study hours: 210 h	

Responsibility
Head of the Department of Statistical Physics
Teaching units (SWS / tutorial hours / private study hours)
- Lecture “Statistical Mechanics of Deep Learning” (4 SWS / 60 h / 90 h) - Seminar “Statistical Mechanics of Deep Learning” (2 SWS / 30 h / 120 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*

Objectives

Students acquire knowledge of the fundamental insights of statistical mechanics in the functioning of neural networks. Here physical techniques are used, which are also used to analyze interacting interacting spin systems. With the acquired students gain insights into the functioning of deep neural networks. neural networks. They will be able to understand specialist literature on the statistical analyze neural networks, to discuss and evaluate them.

Content

Structure of deep neural networks, back-propagation algorithm, training of neural networks using the MNIST data set as an example, analysis of Gibbs and online learning of a perceptron in the teacher-student configuration, calculation of quenched averages using the replica method, analysis of two-layer networks using the example of the committee machine, bias-variance tradeoff, random matrix theory and analysis of weight matrices, application of neural networks to solve physical problems

References

- A. Engel and C. van den Broeck, Statistical Mechanics of Learning, Cambridge University Press

Practical Course: Quantum Statistical Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	every semester	**12-PHY-MWPTKM5** **5 CP**
Workload: 150 h	Tutorial hours: 30 h	Private study hours: 120 h	
Responsibility: Head of the Quantum Statistical Physics Group			
Teaching units (SWS / tutorial hours / private study hours): - Practice "Practical Course: Quantum Statistical Physics" (2 SWS / 30 h / 120 h)			
Participation requirements: None			
Examinations (duration; weighting) and pre-examination requirements: Project work (written report with preparation time 4 weeks, oral presentation of 45 min; ×1)			

Objectives
In parallel to the modules 12-PHY-BW3QN1 or 12-PHY-MWPSTP1, autonomous theoretical work (practicing analytical and numerical techniques, literature research, model building, problem solving, etc.) on some actual research project will be practiced under supervision. The results will be discussed in the working group and presented both in oral and written form.

Content
The contents of the module are adapted to the interests and the level of knowledge of the students. The following topics are available for selection: mesoscopic physics, quantum field theory of many-particle systems.

References
Recommendations for references and literature will follow in the course.

Black Holes

Module type	Recommended for	Module availability	Module number and ECTS
elective	6^{th}/ 7^{th}/ 8^{th} semester	irregular cycle	**12-PHY-MWPMMP1** **10 CP**
Workload 300 h	Tutorial hours 90 h	Private study hours 210 h	
Responsibility Head of the Department Mathematical Physics			
Teaching units (SWS / tutorial hours / private study hours) - Lecture "Black Holes" (4 SWS / 60 h / 80 h) - Exercise "Black Holes" (2 SWS / 30 h / 130 h)			
Participation requirements None			
Examinations (duration; weighting) and pre-examination requirements Written exam (120 min; ×1) *Pre-examination requirements: Weekly exercises with tasks related to the module content. Points are awarded for solutions. 50% of the total points for the entire semester have to be achieved as prerequisite for admission to the exam.*			

Objectives

After active participation in the module, students will be able to
- articulate and demonstrate a thorough understanding of the essential principles and techniques concerning the properties of black holes in the theory of general relativity,
- derive geometrical and analytical key features of the Einstein's equations of general relativity,
- independently work on and solve relevant model problems and justify their approach.

Content

- geometric properties of key special black hole solutions of the Einstein equations, including the Schwarzschild, Reissner-Nordström and Kerr solutions;
- fundamentals of causality theory, Lorentzian geometry and Penrose diagrams;
- the initial value problem in general relativity;
- asymptotic flatness and conservation variables;
- the incompleteness theorems of Penrose and Hawking;
- the Cosmic Censorship conjectures;
- the laws of black hole mechanics;
- dynamic properties of black holes.

References

- S. W. Hawking and G.F.R. Ellis, The large scale structure of space-time, Cambridge University Press, 1973;
- R.M. Wald: General Relativity, University of Chicago Press, 1984

Group Theory and Its Applications in Physics

Module type	Recommended for	Module availability	Module number and ECTS
elective	6th/ 7th/ 8th semester	irregular cycle	**12-PHY-MWPXT1** **10 CP**
Workload 300 h	Tutorial hours 90 h	Private study hours 210 h	

Responsibility
Head of the Department of Quantum Field Theory and Gravitation
Teaching units (SWS / tutorial hours / private study hours)
- Lecture "Group Theory and Its Applications in Physics" (4 SWS / 60 h / 80 h) - Exercise "Group Theory and Its Applications in Physics" (2 SWS / 30 h / 130 h)
Participation requirements
None
Examinations (duration; weighting) and pre-examination requirements
Written exam (180 min; ×1)

Objectives

After active participation in the module, students will be able to:

- present and explain the basic terms, concepts and methods of group theory both orally and in written form
- apply them to the description and application of symmetries in different areas of physics
- work on and solve simple model problems autonomously and justify their approach

Content

- Basic concepts of group theory: groups, homomorphisms, group action
- Finite groups, molecular symmetries, point groups and crystal lattices
- Representation theory of finite and compact groups (up to Peter-Weyl's theorem)
- Lie groups and Lie algebras (matrix groups only)
- Rotation group and its representations (including spinor representations)
- Representations of the permutation group
- Applications in quantum theory: Wigner's first theorem, angular momentum and spin, Clebsch-Gordan, selection rules, identical particles, NMR spectra, nuclear models, multipletts of elementary particles
- Some on representation theory of non-compact groups: Lorentz group and Poincaré group (optional: induced representations, semidirect products, Wigner's classification of elementary particles)

The course will be taught in English. Study and examinations have to be done in English.

References

- A. O. Barut, R. Raczka: Theory of group representations and applications, PWN Warsaw, 1977
- M. Hamermesh: Group theory and its application to physical problems, Addison-Wesley Reading-London, 1962
- S. Sternberg: Group theory and physics, Cambridge University Press, 1994

2.9 Bachelor Thesis Colloquium

Bachelor Thesis Colloquium

Module type	Recommended for	Module availability	Module number and ECTS
elective	8th semester	every semester	**12-PHY-BICOL 5 CP**
Workload: 150 h	Tutorial hours: 15 h	Private study hours: 150 h	
Responsibility: Study Program Responsible			
Teaching units (SWS / tutorial hours / private study hours): - Colloquium “Bachelor Thesis Colloquium” (1 SWS / 15 h / 135 h)			
Participation requirements: Submitting the Bachelor Thesis			
Examinations (duration; weighting) and pre-examination requirements: Presentation with discussion (45 min; ×1)			

Objectives

In preparation for the colloquium, students will broaden their knowledge in scientific writing and improve their presentation skills. In the colloquium, students have to demonstrate that they are able to present the technical content, the methodology and the results of the bachelor thesis in a medial way and that they are able to present and explain them in an oral presentation.

Content

The colloquium module complements the Bachelor Thesis, which is written on a current field of research in physics. Complementary to the research phase of the Bachelor Thesis, the students will train their basic scientific writing skills. They will improve the presentation techniques learned in the advanced seminar by regularly reporting on the progress of their Bachelor's thesis in the department seminars. This includes the presentation of the content to researchers of the respective field of specialization, but also to researchers from related fields.

Note on the Colloquium: TheCcolloquium is public and includes a presentation (duration 30 min.) and the discussion on the written work (duration 15 min.).

References

References of the current research literature, which are given at the beginning of the Bachelor Thesis.