Curriculum for the Master's Degree Programme

Technical Physics

Curriculum 2017 in the version of 2023

This curriculum was approved by the Senate of the University of Graz at the meeting of May 17, 2023, and by the Senate of Graz University of Technology at the meeting of May 22, 2023.

The degree programme is organised as a combined degree programme (§ 54 (e) UG) of the University of Graz (Uni Graz) and Graz University of Technology (TU Graz) in the context of "NAWI Graz". The legal bases of this degree programme are the Universities Act 2002 (UG) and the Legal Regulations for Academic Affairs in the statutes of TU Graz and Uni Graz, as amended.

Please note: the English version of this document is a courtesy translation. Only the German version is legally binding.

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I General Information

§ 1. Subject matter of degree programme and qualification profile

The engineering sciences Master's Degree Programme Technical Physics comprises four semesters. The total scope of the programme is 120 ECTS credits.

The Master's Degree Programme Technical Physics is held in English.

Graduates of this study programme are awarded the academic degree ‘Diplom-Ingenieurin’ or ‘Diplom-Ingenieur’, abbreviated as ‘Dipl.-Ing.’ or ‘DI’. The international equivalent of this university degree is ‘Master of Science’, abbreviated as ‘MSc’.

(1) Object of degree programme

The English-language Master's Degree Programme Technical Physics, which is offered jointly by Graz University of Technology and the University of Graz, provides students with a scientific and technical education in the subject of physics.

Physics significantly shapes our current worldview and forms the basis for other sciences and technologies. Accordingly, the study of technical physics is dedicated to researching fundamental relationships in physics, finding answers to fundamental questions in the physical world and applying physical methods to technical problems. This degree programme is designed to teach students how to think logically and how to apply methods for problem solving. It is typical of the study of technical physics that, in addition to a solid physical and mathematical education, application-oriented subjects with a focus on technology and computer methods are also offered. With the addition of business and social skills, the students are provided with a well-rounded education that provides key qualifications crucial for their future professional careers.

The use of spoken and written English as the lingua franca in science, technology and business is of fundamental importance, which is why the degree programme is entirely held in English.

(2) Qualification profile and skills

Knowledge and understanding
After completing the Master's Degree Programme Technical Physics, graduates have mastered and are able to apply complex scientific methods. They able to describe and interpret special aspects, boundaries, terminology and schools of thought in their subject area.

Graduates have deepened their subject-specific knowledge in one of the following areas:

- Statistical and Computational Physics
- Advanced Quantum Mechanics and Atom Physics
- Advanced Solid-State Physics and Radiation Physics

and have learned the fundamentals of business and entrepreneurship.

Depending on their choice of specialization, they will have acquired and learned to apply in-depth knowledge in several of the following 13 subject areas:

- applied materials physics, semiconductor devices, surface science
- computational condensed matter physics, modelling of materials, theoretical Solid-State physics, quantum many-body physics
- nanoscience, nano and laser optics, quantum optics and molecular physics
- radiation and plasma physics, laboratory technology and instrumentation, microscopy and nanoanalysis

Knowledge-based application and assessment

Graduates of the Master's Degree Programme Technical Physics can

- specialise in a particular field of technical physics in such a way that they can connect to current international research.
- work independently on scientific and engineering tasks.
- apply modern scientific methods and analyse complex processes with current computer simulation methods.
- also work professionally outside of their field of specialization from the master's degree programme due to their extensive fundamental knowledge in technical physics and put the learned scientific methods and problem-solving strategies to use in new and unfamiliar situations.
- work on problems in other branches of science (e.g., mathematics, chemistry, medicine and environmental systems science).

Communicative, organisational and social competences

Graduates are equipped with basic skills required to further develop critical and analytical approaches based on their professional competence, to independently acquire new knowledge and to work in a targeted manner in research and application-oriented tasks.

They can handle difficulties in projects and, if necessary, reach their goal by modifying their strategy.

In addition, they are able to comprehensively document their results and solution strategies, put them in the context of current international research and convey them using modern communication and presentation techniques.

Through interdisciplinary training, graduates acquire the ability to work interdisciplinary and communicate effectively in project teams.

They are aware of their responsibility towards science and the possible consequences of their work for the environment and society.

(3) **Need and relevance of the degree programme for science and the labor market**

In addition to their general excellent professional qualifications, physicists have what is often referred to as ‘physical thinking’, that is valuable core competences resulting from a combination of solid scientific knowledge, familiarity with practical methods (experimental, theoretical and computer-oriented), highly analytical thinking skills and pronounced problem-solving skills. They are therefore considered to be universal problem solvers, especially in innovative sectors, are characterised by a high degree of flexibility both in terms of career orientation and sector, and can be widely deployed in industry, business and science.

Physicists are primarily active in the following sectors:

- Universities and other educational and research institutions
- Data processing
- Electronics and electrical engineering
- Precision engineering and optics
- Machine and automotive manufacturing
- Healthcare and public administration
- Services for businesses

The master’s degree programme also provides students with the skills required for independent scientific work within the framework of a doctoral programme.

II General Provisions

§ 2. Admission requirements

(1) The Master's Degree Programme Technical Physics builds on the Bachelor’s Degree Programme Physics offered by NAWI Graz. Graduates of this bachelor’s degree thus meet the admission requirements for the Master's Degree Programme Technical Physics. Furthermore, the following degree programmes are eligible for admission to the Master's Degree Programme Technical Physics without further requirements:

- Any bachelor's degree programme in physics and/or technical physics of a higher educational institution in one of the following countries: Belgium, Bulgaria, Denmark, Germany, Estonia, Finland, France, Greece, Ireland, Italy, Iceland, Croatia, Latvia, Lichtenstein, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Austria, Poland, Portugal, Romania, Sweden, Switzerland, Slovakia, Slovenia, Spain, the Czech Republic, Hungary, the United Kingdom and Cyprus.

(2) Any degree programmes that are not mentioned in (1) are considered eligible for admission if at least 105 ECTS credits have been positively completed in the following subject areas:

- 35 ECTS credits from courses on experimental physics
- 30 ECTS credits from courses on theoretical physics
- 35 ECTS credits from courses on mathematics
- 5 ECTS credits from courses on programming

(3) Any degree programmes that do not satisfy (1) or (2) are not considered equivalent to this degree programme. However, if at least 75 ECTS credits have been completed in the subject areas mentioned in (2), full equivalence may be established by requiring supplementary examinations. The extent of these supplementary examinations must not exceed 30 ECTS credits.

(4) Any degree programmes that do not satisfy (1), (2) or (3) are not close enough in subject matter to establish full equivalency. In such cases, admission to the Master’s Degree Programme Technical Physics is not possible.

(5) Proof of sufficient English language skills is a prerequisite for admission to the degree programme. The type of proof required is specified in a regulation issued by the rectorate.

§ 3. Allocation of ECTS credits

All study activities completed by the students are allocated certain numbers of ECTS credits. ECTS credits reflect the workload of each course or assignment relative to the workload of an academic year, which is intended to be 1500 real hours corresponding to 60 ECTS credits (i.e., 25 actual hours per 1 ECTS credit). This workload includes both the time spent in self-study and the classroom hours. One semester course hour is equivalent to 45 minutes per week of the semester.

§ 4. Structure of the degree programme

The Master's Degree Programme Technical Physics with a workload of 120 ECTS credits covers four semesters and is structured in modules, as follows:

	ECTS
Compulsory Module A: Statistical and Computational Physics	10
Compulsory Module B: Advanced Quantum Mechanics and Atom Physics	10
Compulsory Module C: Advanced Solid-State Physics and Radiation Physics	10
Compulsory Module D: Business and Entrepreneurship	4.5
3 physics-focused Specialization Modules (9 ECTS each)	27
Elective Topics	15
Free Electives	10.5
Master’s seminar	2
Master’s thesis	30
Master’s examination	1
Total	120

§ 5. Types of courses

The types of courses provided at Uni Graz and TU Graz are regulated by the statutes of these universities.

§ 6. Group sizes

The following maximum numbers of participants (group sizes) are stipulated for the following types of courses:

(1) For exercises (UE) and for the exercise parts of lectures with integrated exercises (VU), the maximum group size is 25. For any laboratory exercises that are part of lectures with integrated exercises (VU), the maximum group size is 6.

(2) For laboratory courses (LU) the maximum group size is 6.

(3) For projects (PT) and seminars (SE) the maximum group size is 20.

§ 7. Guidelines for the allocation of places in courses

(1) If the number of students exceeds the number of available places, students are allocated places in the course according to the following priority criteria, whereby the individual criteria are to be applied in the order given:

a. Position of the course in the curriculum (acc. to § 8 and § 9): Priority is given to students for whom the course is compulsory according to their curriculum over those who are taking the course as part of an elective module.

b. Total of completed/recognized ECTS credits for the degree programme: All study achievements completed in the degree programme for which the student wants to take the course are taken into account for the ranking. Students with the highest total of ECTS credits already completed in their current degree programme are ranked preferentially.

c. Number of semesters spent studying in the degree programme so far: Students are ranked according to the number of semesters they have already studied in the degree programme, whereby priority is given to those who have studied longer.

d. Decision by lot: If it is not possible to rank students according to the above criteria, admission to the course is decided by lot.

(2) Up to 10% of the existing places in the course are reserved for students completing part of their studies at a NAWI Graz university as part of a mobility programme.

III Course Content and Structure

§ 8. Modules, courses and semester

The individual courses of this master's degree programme and their designation as compulsory and elective modules are set out below. The knowledge, methods or skills to be taught in each course are described in detail in Appendix I. The assignment of courses to particular semesters is a recommendation and ensures that the sequence of courses is best able to build on prior knowledge and that the workload of an academic year does not exceed 60 ECTS credits. The allocation of the courses to the participating universities is defined in Appendix II and § 9.

Master's Degree Programme Technical Physics								
Module	**Course**				**Sem. ECTS credits**			
		SSt.	**Type**	**ECTS**	**I**	**II**	**III**	**IV**
Compulsory Module A: Statistical and Computational Physics								
	Statistical Physics[1]	2	VO	4	4			
	Statistical Physics[1]	1	UE	2	2			
	Computer Simulations	3	VU[3]	4		4		
Subtotal Compulsory Module A		**6**		**10**	**6**	**4**	**0**	**0**
Compulsory Module B: Advanced Quantum Mechanics and Atom Physics								
	Advanced Quantum Mechanics[1]	2	VO	4	4			
	Advanced Quantum Mechanics[1]	1	UE	2	2			
	Advanced Atomic and Molecular Physics	2	VO	4		4		
Subtotal Compulsory Module B		**5**		**10**	**6**	**4**	**0**	**0**
Compulsory Module C: Advanced Solid-State Physics and Radiation Physics								
	Advanced Solid-State Physics	3	VO	6	6			
	Radiation Physics	2	VO	4		4		
Subtotal Compulsory Module C		**5**		**10**	**6**	**4**	**0**	**0**
Compulsory Module D: Business and Entrepreneurs								
Completion of either D.1 or D.2 together with D.3.								
D.1	Encyclopedia Business Economics	3	VO	4.5		4.5		
D.2	Enabling Innovation	1	VO	1.5		1.5		
D.3	Enabling Innovation	2	UE	3		3		
Subtotal Compulsory Module D				**4.5**	**0**	**4.5**	**0**	**0**
Total of Compulsory Modules				**34.5**	**18**	**16.5**	**0**	**0**
3 physics-focused Specialization Modules (9 ECTS each acc. to § 9 (A))				27				0
Elective Topics acc. to § 9 (B)				15				0
Total of Elective Modules described under § 9				**42**	**9**	**9**	**24**	**0**
Master's seminar[4, 5]				**2**				2
Master's thesis				**30**				30

Master's examination	**1**				1
Free Electives acc. to § 10	**10.5**	**3**	**4.5**	**3**	0
Overall total	**120**	**30**	**30**	**27**	**33**

[1]: This module is held together with the Master's Degree Programme Physics.
[2]: 2/3 lecture part, 1/3 exercise part
[2]: 1/3 lecture part, 2/3 exercise part
[4]: This course is assessed as "successful completed" or as "not completed".
[5]: Students who complete the master's seminar at TU Graz or Uni Graz must choose the seminar in consultation with the supervisor for their master's thesis.

§ 9. Elective modules

A. Specialization Modules

Students must choose a total of 3 physics-focused Specialization Modules and complete exactly 3 courses from each selected Specialization Module. In any given Specialization Module, the courses marked with (◆) are compulsory. With the exception of the courses "Measurement Techniques and Probe Analysis" and "Computer Supported Measurement Techniques" (Module G), which can also be taken as part of the Elective Topics, any other laboratory courses (LU) can only be taken by students who have selected the respective Specialization Module. Students may take any of the other laboratory courses (LU) within their selected Specialization Module beyond the 3 courses they must take for the completion of the Specialization Module if the maximum number of participants in the course has not been reached.

Physics-focused Specialization Modules (in alphabetical order)							
Module/course				Semester		Uni Graz[1]	TU Graz[1]
	SSt.	**Type**	**ECTS**	**WS**	**SS**		
Module E: **Applied Materials Physics**							
◆ Research Laboratory Applied Materials Physics	2	LU[4]	3	X	X		X
Functional Materials	2	VO	3	X			X
Soft Matter Physics	2	VO	3		X		X
Structurally Complex Materials	2	VO	3	X			X
Structural Transformations and Diffusion in Materials	3	VU[2]	3		X		X
Module F: **Computational Condensed Matter Physics**							
◆ Research Laboratory Advanced Computational Physics	2	LU	3	X	X		X
Numerical Simulation of Strongly Correlated Many-Body Models	2	VU[2]	3	X			X
Quantum Dynamics	2	VU[2]	3	X			X
Ab-Initio Methods for Correlated Materials	2	VO	3	X			X
Computational Methods in Nano Physics	2	VU[2]	3		X	X	
Module G: **Laboratory Technology and Instrumentation**							

Physics-focused Specialization Modules (in alphabetical order)							
Module/course				Semester		Uni Graz[1]	TU Graz[1]
	SSt.	Type	ECTS	WS	SS		
One of the two laboratory exercises (LU) must be completed:							
◆ Measurement Techniques and Probe Analysis	2	LU[4]	3	X	X		X
◆ Computer Supported Measurement Techniques	2	LU	3	X			X
Vacuum Technology	2	VO	3	X		X	X
X-Ray and Neutron Scattering	2	VO	3		X		X
Ultrasound Methods	2	VO	3		X	X	
Signal Theory and Signal Processing	2	VU[2]	3		X	X	X
Optical Measurement Techniques	2	VO	3	X			X
Tomography for Materials Characterization	2	VO	3		X	X	X
Module H: **Microscopy and Nanoanalysis**							
◆ Electron Microscopy 1	2	VO	3	X			X
◆ Advanced 2D and 3D Nanoanalysis	2	VU[2]	3		X		X
Electron Microscopy 2	2	VO	3		X		X
Structuring of Material Surfaces and Functional Nanofabrication	2	VO	3	X			X
X-Ray and Neutron Scattering	2	VO	3		X		X
Research Laboratory Microscopy and Nanoanalysis	2	LU[4]	3	X	X		X
Module I: **Modelling of Materials** [3]							
◆ Fundamentals of Electronic Structure Theory	2	VO	3	X		X	
◆ Simulating Materials Properties from First Principles	2	UE	3		X	X	X
Applications of Electronic Structure Methods	2	VO	3		X		X
Ab-Initio Methods for Correlated Materials	2	VO	3	X			X
Advanced Electronic Structure Theory	2	VO	3		X		X
Modelling of Molecular Systems	2	VO	3	X			X
Module J: **Nano- and Laser-Optics**[3]							
◆ Optics – A Photonics Perspective	2	VO	3	X		X	
◆ Research Laboratory Nano and Laser Optics	2	LU[4]	3	X	X	X	X
Nano Optics	2	VO	3		X	X	
Laser Physics	2	VO	3	X		X	
Ultrafast Laser Physics	2	VO	3		X		X
Module K: **Nanoscience**							
◆ Nanostructures and Nanotechnology	2	VO	3		X		X
◆ Research Laboratory Nanoscience	2	LU[4]	3	X	X		X
Chemical Fundamentals of Nanoscience	2	VO	3	X			X
Theory of Magnetism and Collective Phenomena	2	VO	3	X			X
Functional Nanofabrication	2	VO	3				X
Theoretical Nano- and Quantum-Optics	2	VO	3		X	X	
Module L: **Quantum Many-Body Physics**							

Physics-focused Specialization Modules (in alphabetical order)							
Module/course				Semester		Uni Graz[1]	TU Graz[1]
	SSt.	Type	ECTS	WS	SS		
◆ Quantum Theory of Many-Body Systems	2	VU[2]	3		X	X	X
Introduction to Correlated Many-Body Systems	2	VU[2]	3	X			X
Many-Body Systems out of Equilibrium	2	VU[2]	3	X			X
Open Quantum Systems	2	VU[2]	3	X			X
Module M: **Quantum Optics and Molecular Physics**[3]							
◆ Optics – A Spectroscopy Perspective	2	VO	3	X			X
◆ Research Laboratory Quantum Optics and Molecular Physics	2	LU[4]	3	X	X	X	X
Laser Physics	2	VO	3	X		X	
Ultrafast Laser Physics	2	VO	3		X		X
Quantum Optics	2	VO	3		X		X
Modelling of Molecular Systems	2	VO	3	X			X
Module N **Radiation and Plasma Physics**							
◆ Applied Radiation Physics	2	VO	3	X			X
◆ Research Laboratory Radiation and Plasma Physics	2	LU[4]	3	X			X
Plasma Physics	2	VO	3	X			X
Fusion Physics	2	VO	3	X			X
Kinetic Theory in Plasma Physics	2	VO	3		X		X
Module O: **Semiconductor Devices**							
◆ Physics of Semiconductor Devices	2	VO	3	X			X
◆ Research Laboratory Semiconductor Devices	2	LU[4]	3	X	X		X
Microelectronics and Micromechanics	2	VO	3		X		X
Organic Semiconductors	2	VO	3		X		X
Modelling and Simulation of Semiconductors	2	VU	3		X		X
Module P: **Surface Science**							
◆ Surface Science	2	VO	3	X		X	
◆ Research Laboratory Surface Science	2	LU[4]	3		X	X	X
Molecular Interfaces	2	VO	3		X	X	
Scanning Probe Techniques	2	VO	3		X	X	
Synchrotron Radiation Techniques	2	VO	3	X		X	
Thin Film Science and Processing	2	VO	3		X		X
Surface Chemistry	2	VO	3		X		X
Vacuum Technology	2	VO	3	X		X	X
Module Q: **Theoretical Solid-State Physics** [3]							
Quantum Theory of Many-Body Systems	2	VU[2]	3		X	X	X
Fundamentals of Electronic Structure Theory	2	VO	3	X		X	
Theory of Magnetism and Collective Phenomena	2	VO	3	X			X
Theory of Superconductivity	2	VO	3	X			X
Phase Transitions and Critical Phenomena	2	VO	3	X			X

Physics-focused Specialization Modules (in alphabetical order)							
Module/course				Semester		Uni Graz[1]	TU Graz[1]
	SSt.	Type	ECTS	WS	SS		
Module R: **Photon Science**[3]							
◆ Research Laboratory Photon Science	2	LU[4]	3	X	X	X	X
Laser Spectroscopy	2	VO	3	X			X
Structured Light and Nanoscale Wave Phenomena	2	VO	3	X		X	
Photonics: Light, Matter, and Time	2	VO	3		X		X
Optical Waveguides, Photonic Circuitry and Applications	2	VO	3		X	X	
Optical Measurements Techniques	2	VO	3	X			X

[1]: Assignment of the course to the participating universities. Both universities are named if the course is offered at both universities in combination, in parallel or alternately.

[2]: 2/3 lecture part, 1/3 exercise part

[3]: This module is part of the curriculum for both the Master's Degree Programme Technical Physics and the Master's Degree Programme Physics.

[4]: This laboratory course (LU) has a maximum group size of 3 people.

B. Elective Topics

Within the framework of the Elective Topics, courses worth 15 ECTS credits must be completed.

The following courses can be chosen:

- Any courses from the course catalogue of one of the above-mentioned Specialization Modules that the student has not already completed as part of the 3 compulsory courses for the Specialization Module (see explanations under point A Specialization Modules).
- Any compulsory and elective courses of the NAWI Master's Degree Programme Physics provided the student meets the respective course requirements.
- Any foreign language courses (English or German language courses only if the student is not a native speaker of the respective language) worth a maximum of 3 ECTS credits.
- Courses from the course catalogue “Further Elective Topics” below.
- German-language courses from the course catalogue “Bachelor's Degree Programme Physics” below.

Course catalogue: Further Elective Topics							
Course		Course		Semester		Uni Graz[1]	TU Graz[1]
	SSt.	Type	ECTS	WS	SS		
Master’s project[2]	0.5	PT	6	X	X	X	X
Special Topics of Technical Physics: [subheading][3]							X
Software Engineering in Physics	4	VU[4]	4	X			X

Course catalogue: Further Elective Topics							
Course		Course		Semester		Uni Graz[1]	TU Graz[1]
	SSt.	**Type**	**ECTS**	**WS**	**SS**		
MATHEMATICA for Theoretical Physics: Symbolic and Numerical Computation	4	VU[4]	4		X		X
Kinetic Equations for Classical and Quantum Mechanical Systems	2	VO	3	X			X
Advanced Statistical Physics	2	VO	3	X		X	X
Functional Materials II	0.66	VO	1		X		X
Physics of Sustainable Energy	2	VO	3	X			X
Weltraumplasmaphysik[6,7]	1	VO	2		X		X
Fortgeschrittene Weltraumplasmaphysik[6,7]	1	VO	2		X		X
Aktive Plasmaexperimente im Weltraum[6,7]	1	VO	2		X		X
Business and Entrepreneurship:							
Encyclopedia Business Economics	2	UE	2		X		X
Product Innovation Project [5]	3	PT	5	X			
Product Innovation Project 2	2	PT	3		X		
Implementation Innovation Strategy Through Merger & Acquisition – Essential for Engineers	2	SE	3	X			X
Patentrecht[6]	2	VO	3	X			X

[1]: Assignment of the course to the participating universities. Both universities are named if the course is offered at both universities in combination, in parallel or alternately.

[2]: This project is designed to prepare for the master's thesis. Only the course taught by the student's supervisor for the master's thesis can be taken.

[3]: Courses with the title "Special Topics of Technical Physics (subheading)" can be taken as part of the Free Electives, with 1 semester course hours per week usually corresponding to 1.5 ECTS credits. These courses have descriptive subheadings and are offered with a total scope of 1–3 semester course hours for a lecture-type course (VO) or 1–2 semester course hours for a lecture with integrated exercises (UE). Courses with different subheadings must be classified as different courses.

[4]: 1/3 lecture part, 2/3 exercise part

[5]: This course can be recognized for the Compulsory Module D Business and Entrepreneurship.
[6]: This course is held in German.
[7]: This course is offered every two years.

Course catalogue: Bachelor's Degree Programme Physics							
Course		Course		Semester		Uni Graz[1]	TU Graz[1]
	SSt.	Type	ECTS	WS	SS		
Physikalische Grundlagen der Materialkunde[2]	3	VO	4.5		X		X
Kontinuumsphysik[2]	2	VU[3]	3		X		X
Kryotechnik, Vakuumtechnik und Analysemethoden[2]	3	VO	4.5		X		X
Moderne Kapitel der Theoretischen Physik[2]	2	VU[3]	3		X	X	
Moderne Kapitel der Experimentellen Physik[2]	2	VU[3]	3		X	X	
Einführung in die Astrophysik[2]	2	VO	3	X		X	
Einführung in die Geophysik[2]	2	VO	3		X	X	
Einführung in die Meteorologie und Klimaphysik[2]	2	VO	3	X		X	

[1]: Assignment of the course to the participating universities. Both universities are named if the course is offered at both universities in combination, in parallel or alternately.

[2]: This course is held in German. Recommended for students who have not studied physics in the NAWI Bachelor's Degree Programme Physics.

[3]: 2/3 lecture part, 1/3 exercise part

§ 10. Free Electives

(1) The courses to be completed as part of the Free Electives in the Master's Degree Programme Technical Physics are designed to provide individual strategic focus and further development of the students. They may be freely selected from the courses offered by any recognized national or international university and also recognized national post-secondary educational institutions. Appendix III contains recommendations for specific free-choice courses.

(2) If a free-choice subject does not have an allocation of ECTS credits, each semester course hour (SSt) of this course is counted as one ECTS credit point. However, if such courses are lecture-type courses (VO), they are assigned 1.5 ECTS credits for each semester course hour.

(3) Additionally, the possibility exists, in accordance with § 13, to take a professionally-oriented internship or short study periods in foreign countries as part of the Free Electives.

§ 11. Master’s thesis

(1) The purpose of the master’s thesis is to demonstrate the student’s ability to work on scientific topics on their own, both with regard to content and methodology. The scope of the master's thesis must be determined in such a way that its completion can be reasonably and feasibly accomplished by the student within a period of six months.

(2) The topic of the master’s thesis must belong to one of the compulsory or elective modules in the subject area of physics. Any exceptions are subject to approval by the dean of studies.

(3) The master's thesis must be registered before beginning work on it via the Dean's office. The subject, the field to which the subject is assigned, and the supervisor must be stated along with the name of the institute.

(4) 30 ECTS credits are allocated to the master's thesis.

(5) The master's thesis must be submitted for assessment in electronic form.

§ 12. Admission requirements for courses/examinations

(1) Admission to the master's degree examination before a committee requires proof of the positive assessment of all examination results according to § 8 and § 9 above and also proof of the positive assessment of the master's thesis.

(2) Students who, according to § 2, have to fulfil the specific admission requirements in order to be able to study in the Master's Degree Programme Technical Physics must have successfully completed these admission requirements before participating in laboratory exercises (LU) and lectures with integrated exercises (VU), which carry out part of the exercises as laboratory exercises.

§ 13. Stays abroad and internships

(1) Recommended stays abroad

It is recommended for students to spend one semester abroad in the course of their studies. In this master's degree programme, the 2nd or 3rd semesters are particularly suitable for this purpose. Courses taken during the study period abroad will be recognized by the dean of studies if they are equivalent. On the recognition of examinations taken during study periods abroad, we refer to § 78 (5) Universities Act 2002 (UG).

It is also possible to obtain recognition of work done in shorter study periods abroad, for example participation in summer or winter schools, as part of the Free Electives, by application to the dean of studies.

(2) Internships

It is possible to include professionally-oriented internships in Free Electives.

Each week of full employment corresponds to 1.5 ECTS credits. Active participation in an academic event may also count as an internship. This work experience must be relevant to the degree programme and must be approved by the dean of studies.

IV Examination Regulations and Completion of Studies

§ 14. Examination regulations

Courses are assessed individually.

(1) Examinations for courses held in the form of lectures (VO) must cover the entire contents of the course. Examinations can be oral-only, written-only or a combination of oral and written.

(2) In courses of the types lectures with integrated exercises (VU), exercises (UE), laboratory courses (LU), design exercises (KU), field exercises (FU), projects (PT), seminars (SE), seminar projects (SP) and excursions (EX), students' performance is measured by continuous assessment of work done by the students and/or by ongoing tests. The assessment must be based on at least two evaluations of different aspects of the course.

(3) If a module is made up of multiple courses, the overall grade for the module is to be calculated as follows:

a. The grade of each course belonging to the module is multiplied by the corresponding ECTS credits.
b. The values calculated in point (a) are added together.
c. The result of the addition is divided by the sum of the ECTS credits of the courses.
d. The result of the division is rounded to a whole-numbered grade, if necessary. The grade must be rounded up if the decimal place exceeds 0.5. Otherwise, the grade must be rounded down.
e. A positive module grade may only be awarded if each individual course has been assessed as positive.
f. Courses whose assessment consists only of "successful/unsuccessful participation" are not included in the calculation under points (a) to (d).

(4) Regulations on repeating assessments for courses with continuous assessment are set out in the statues of TU Graz and Uni Graz.

(5) The master's examination before a committee consists of

- the presentation of the master's thesis (max. 20 minutes),
- the defence of the master's thesis (examination interview),
- an oral examination on topics from an experimental-focus module and a theoretical-focus module according to § 8 and § 9. Computer-focused modules are considered part of the theoretical-focus modules. The master's thesis is assigned to one of the two modules.

The modules are determined by the dean of studies of the university of admission based on the candidate's suggestion. The total duration of the master's examination before a committee is usually 60 minutes and must not exceed 75 minutes.

(6) The examination committee for the master's examination includes the supervisor of the thesis and two other members who are nominated by the dean of studies, after considering suggestions from the candidate, if any. The examination committee must be chaired by one of the members who is not the supervisor of the thesis.

(7) The examination committee determines the grade of this oral examination.

§ 15. Completion of studies

(1) The master's degree programme is completed once the student has achieved positive grades for the courses of all compulsory and elective modules as well as for Free Electives, the master's thesis and the master's examination before the committee.

(2) A degree certificate is issued upon successful completion of the master's degree programme. The master's degree certificate is composed of:

a. a list of all the modules (examination subjects) as set out in § 4 (along with their ECTS credits but without the module ID) and their assessment results,

b. the title and assessment of the master's thesis,

c. the assessment of the final master's examination before a committee,

d. the total of the ECTS credits in Free Electives as defined in § 10, and

e. the overall assessment.

V Validity and Transitional Regulations

§ 16. Legal validity

This Curriculum 2017 in the version of 2023 (UNIGRAZonline version 2023W, TUGRAZonline version 2023W) enters into force on 1 October 2023.

Curriculum	Version	UNIGRAZonline Version	TUGRAZonline Version	Published in the Uni Graz University Gazette	Published in the TU Graz University Gazette
2017	2023	2023W	2023W	31/05/2023	31/05/2023

§ 17. Transitional regulations

Students of the Master's Degree Programme Technical Physics who are subject to the curriculum in the version from 2017 at the time when these changes to the curriculum come into force on 1 October 2023, will be subject to the 2023 version of the curriculum as of 1 October 2023.

Appendices to the curriculum of the

Master's Degree Programme Technical Physics

Appendix I Module Descriptions

Compulsory Module Descriptions

Compulsory Module:	Statistical and Computational Physics
ECTS credits	10
Contents	Statistical Physics: Introduction; probability; classical statistical physics (microcanonical, canonical and grand canonical ensembles, ideal gas, etc.); quantum statistics (density operator, ensembles, Bose-Einstein and Fermi-Dirac statistics, ideal Bose gas, black-body radiation, etc.). Exercises Statistical Physics: Addressing and working out explicit examples of the topics discussed in class. Computational Simulations: Introduction to modern techniques of computer simulations e.g., Markov chain Monte Carlo, optimisations, molecular dynamics, finite element methods.
Learning outcomes	After successfully completing this module, students are able to • understand the basic principles of statistical physics and computational physics. • apply advanced methods in quantum theory. • perform successful standard-type calculations in these fields. After having completed this module, students have • profound knowledge of classical statistical physics and some aspects of quantum statistics. • familiarity with some of the most important methods of computer simulations and their range of application.
Teaching and learning activities and methods	Lectures, exercises with problem sets
Recommended prerequisites for participation	Theory courses at a bachelor’s degree level and knowledge in programming
Frequency in which the module is provided	Every year

Compulsory Module:	Advanced Quantum Mechanics and Atom Physics
ECTS credits	10
Contents	Advanced Quantum Mechanics: • Extension beyond the hydrogen atoms: covalent bond and LCAO, Born-Oppenheimer approximation, van der Waals interaction • Advanced aspects of angular momentum theory: ○ addition of angular momentum

	○ the Wigner-Eckart theorem and selection rules • Identical particles • Particles in a classical electromagnetic field, gauge invariance, Landau levels • Second quantisation (fermions, bosons, electromagnetic field) • Matter/radiation interaction: transition rates, etc. • Scattering theory in one and three dimensions (introductory) • Path integral Exercises Advanced Quantum Mechanics: Addressing and working out explicit examples of the topics discussed in class. Advanced Atomic and Molecular Physics: Interference, laser and high-frequency spectroscopy: principles and experimental setup; basics of theoretical molecular physics: molecular formation, molecular binding, interaction with light, molecular symmetry; rotational, vibrational, and electronic excitations in polyatomic systems; theoretical molecular spectroscopy; short introduction to selected topics of quantum chemistry and cluster physics.
Learning outcomes	After successfully completing this module, students are able to • understand the principles of advanced quantum mechanics, including the composition of angular momenta, identical particles, matter/radiation interaction and scattering theory. • address and solve problems in these fields. • link abstract knowledge to concrete problems in atomic and molecular physics. After having completed this module, students have • an understanding of advanced aspects of quantum mechanics such as angular momentum, identical particles and second quantisation, matter/radiation interaction and scattering theory. • knowledge of classical as well as modern spectroscopic setups and their application to measurements of rotational, vibrational or electronic transitions. • deeper insights into abstract concepts of quantum mechanics through concrete applications in atomic and molecular physics.
Teaching and learning activities and methods	Lectures, exercises
Recommended prerequisites for participation	Knowledge of quantum mechanics and electrodynamics at a bachelor’s degree level
Frequency in which the module is provided	Every year

Compulsory Module:	**Advanced Solid-State Physics and Radiation Physics**
ECTS credits	10
Contents	Advanced Solid-State Physics: Calculation and interpretation of photon, phonon and electron dispersion relations and densities of states, photoemission; determination of the equilibrium thermodynamic properties from the densities of states; electrons in a magnetic field: the quantum Hall effect, the Shubnikov-de Haas effect and the de Haas-van Alphen effect; phase transitions: structural, magnetism, ferroelectricity, piezoelectricity, superconductivity, Peierls transition, Landau theory; optical properties of

	materials: linear response theory, Kramers-Kronig relations, optical absorption, ellipsometry; electrical and thermal transport: Boltzmann equation; crystal symmetries; quasiparticles: plasmons, polarons, polaritons, excitons, magnons, Raman spectroscopy, EELS; electron-electron interactions: Fermi liquid theory, screening, Mott transition, single-electron effects, Hubbard model. Radiation Physics: Basic experimental and theoretical concepts of nuclear physics (scattering of particles by nuclei, nuclear models, nuclear fission); types of ionising radiation (photons, charged and neutral particles), their detection and measurement and their specific interaction with matter; natural radiation sources; effects of ionising radiation on biological systems, dosimetry; concepts of radiation protection and its legal aspects; application of ionising radiation in medicine for diagnosis and therapy; application of nuclear methods in materials science.
Learning outcomes	After successfully completing this module, students are able to • calculate any property of any crystal starting from the microscopic arrangement of the atoms. • understand the principles of radiation physics, incl. radiation detection and dosimetry, radiation protection and application of ionising radiation. After having completed this module, students have • a fundamental understanding of crystalline solids. • basic knowledge of radiation physics and its application.
Teaching and learning activities and methods	Lectures, laboratory exercises, independent project
Recommended prerequisites for participation	Knowledge of Solid-State physics, thermodynamics, electrodynamics, quantum mechanics and experimental physics at a bachelor's degree level
Frequency in which the module is provided	Every year

Compulsory Module:	**Business and Entrepreneurship**
ECTS credits	4.5
Contents	The Compulsory Module Business and Entrepreneurship is an essential element of the Master's Degree Programme Technical Physics, providing students with basic business knowledge that is important for their professional career. Students must take either the Encyclopedia Business Economics lecture or the Enabling Innovation lecture. In the course Encyclopedia Business Economics, students are introduced to business economics, including topics such as financial accounting, marketing, purchasing, human resource management, capital investment and financial management. Moreover, the enterprise is illustrated as a process-orientated value chain. The course Enabling Innovation provides students with basic knowledge of industrial innovation. The following topics are covered: Basics of innovation, models of innovation management, idea generation, idea acceptance, idea

	implementation, innovation marketing, intellectual property rights (IPR), and entrepreneurship. There is the option of taking further courses related to this module within the general module for electives.
Learning outcomes	After successful completion of the course Encyclopedia Business Economics, students have a basic understanding of the principles of business economics. Furthermore, students are able to apply the discussed tools as efficient controlling instruments in enterprises. After successful completion of the course Enabling Innovation, the students have acquired a general understanding of product innovation management and the innovation process. The students know the basic tasks of product innovation management. They are familiar with methods related to the innovation process and are able to choose and apply the learned methods in different situations.
Teaching and learning activities and methods	Lectures, exercises, seminars
Recommended prerequisites for participation	None
Frequency in which the module is provided	Every year

Specialization Module Descriptions

Specialization Module:	**Applied Materials Physics**
ECTS credits	9
Contents	♦ <u>Research Laboratory Applied Materials Physics</u>: Characterisation and analysis of basic structural and functional materials with a focus on current developments in the field of applied materials physics. <u>Functional Materials</u>: Physics and applications of electroceramics, energy materials (batteries, fuel cells, hydrogen storage) and superconductors. <u>Soft Matter Physics</u>: Introduction to colloids, gels, liquid crystals, polymers and some biological systems regarding structural, mechanical and optical properties; hierarchical structures and self-assembly processes. <u>Structurally Complex Materials</u>: Specific, structure-related physical properties of e.g., intermetallic compounds, quasicrystals, amorphous and nanocrystalline materials. <u>Structural Transformations and Diffusion in Materials</u>: Fundamentals of diffusion in e.g., metals, semiconductors, ceramics and ionic conductors in relation to technologically relevant processes.
Learning outcomes	After successfully completing this module, students are able to • understand the foundations of the different materials classes such as metals, ceramics, polymers and composites.

	• assess the relation between the atomic structure, microstructure, kinetic processes and the resulting properties of functional and structural materials. • use modern experimental equipment and methods for the characterisation of materials and the analysis of materials processes. After having completed this module, students have • profound knowledge of different classes of materials and their application as functional and structural materials. • an insight into the application potentials of materials.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Knowledge of experimental physics and Solid-State physics
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Computational Condensed Matter Physics**
ECTS credits	9
Contents	Numerical simulations play a major role in the theoretical treatment of condensed matter problems as well as in quantum chemistry. This module provides an overview of most of the common numerical algorithms and how they are applied to realistic problems. Guided by several examples, results for static and dynamical observables in and out of equilibrium are discussed. The course focuses on the challenging problems encountered in novel materials with an emphasis on correlation effects, which are the driving force for many interesting physical properties such as collective magnetism, Mott insulators, the Kondo effect, giant magnetoresistance, and many more. ♦ <u>Research Laboratory Advanced Computational Physics</u>: Addressing and working out explicit examples of the topics discussed in the lectures described below. <u>Numerical Simulations of Strongly Correlated Many-Body Models</u>: The lecture introduces the models used to describe correlation effects in novel materials and to the numerical approaches to handling the corresponding challenging numerical tasks. The focus in the lecture is on equilibrium properties of models such as the Hubbard, Holstein, Anderson impurity, Kondo and Heisenberg models used to study electronic, phononic and spin degrees of freedom and their mutual interactions. <u>Quantum Computing:</u> Introduction to the time evolution of highly entangled many-body quantum systems; discussion of quantum phenomena and applications; integrability and analytical approaches, mostly in one space dimension; highly efficient representations, numerical techniques; programming and investigation of examples. <u>Ab Initio Methods for Correlated Materials</u>: Introduction to correlations and correlated materials; localised basis sets (Wannier functions); Hubbard

	model and calculation of interaction parameters; (non-)Fermi liquids; the dynamical mean field theory and the Mott-Hubbard transition. Computational Methods in Nano Physics: Computational approaches in solid-state physics, with an emphasis on dynamic processes e.g., spontaneous magnetisation and self-consistency; quantum interference effects in qubit control; spin-selective transport in semiconductor heterostructures; Andreev reflection, etc.
Learning outcomes	After successfully completing this module, students have acquired profound knowledge of how to model the key features of realistic materials. They have obtained an overview of the various numerical simulation techniques and they have learned how to develop large-scale computer codes. Based on the content of the courses in this module, students are able to join international research groups immediately and to collaborate at the forefront of research in condensed matter physics.
Teaching and learning activities and methods	Lectures, exercises and laboratory courses
Recommended prerequisites for participation	Theory courses at a bachelor's degree level and knowledge of advanced quantum mechanics
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Laboratory Technology and Instrumentation**
ECTS credits	9
Contents	♦ Measurement Techniques and Probe Analysis: Selection of advanced laboratory courses in the fields of optics, interferometry, spectrography, physics of lasers, Solid-State and surface physics. ♦ Computer-Supported Measurement Techniques: Laboratory course on the structure, function and programming of a microcontroller in combination with hardware control for automated measurement tasks and process controlling (assembler codes, C-codes, LabVIEW codes). Vacuum Technology: Gas kinetics, pumps, pressure measurements, vacuum chambers, safety. X-Ray and Neutron Scattering: Basic principles of elastic and inelastic scattering techniques to study the structure and dynamics of materials at an atomic and molecular level. Ultrasound Methods: Ultrasound generation, propagation, and behaviour in various media and across interfaces; ultrasound as an analysis tool incl. imaging. Signal Theory and Signal Processing: Introduction to concepts of digital signal processing (spectral analysis and digital filtering, fast transforms, physics of noise, correlation measurement techniques) incl. a laboratory course with practical examples and test programmes for real-time data analysis. Optical Measurement Techniques: Introduction to optical spectroscopy methods for physics, chemistry and biological sciences with focus on providing

	knowledge for estimating applicability ranges of various methods, and on basics of spectroscopy instruments. Tomography for Materials Characterization: Introduction to tomography for material characterisation with focus on electron tomography, photons (X-ray tomography) and photoacoustic tomography.
Learning outcomes	After successfully completing this module, students are able to • understand how physical principles and phenomena can be examined and characterised experimentally. • use and apply modern experimental equipment and methods. After having completed this module, students have • experience of working scientifically by using experimental equipment or connecting experimental hardware for control and analysis by a computer. • the competence and practical knowledge required for the application of various measurement techniques.
Teaching and learning activities and methods	Lectures, lectures with integrated exercises, laboratory courses
Recommended prerequisites for participation	Knowledge of Solid-State physics, experimental and computational techniques at a bachelor’s degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Microscopy and Nanoanalysis**
ECTS credits	9
Contents	Correlating the atomic and nanoscale structure of condensed matter with physical properties and functionality lies at the heart of a wide range of critical technologies. Electron scattering and diffraction instruments are uniquely positioned to address technological challenges with simultaneous spatial, reciprocal and spectroscopic information of a material in two and three dimensions. ♦ Electron Microscopy 1: Overview of electron microscopic instrumentation and techniques; principles of image formation, contrast mechanisms, resolution. ♦ Advanced 2D and 3D Nanoanalysis: Advanced imaging and spectroscopic methods and 3D techniques; aberration-corrected TEM/STEM, electron tomography, electron beam monochromation and applications, EELS data processing and MLLS fitting based mapping; practical exercises. Electron Microscopy 2: Fundamentals of nanoanalytical methods; special chapters about in-situ and atomic resolution applications; industrial applications. Structuring of Material Surfaces and Functional Nanofabrication: The lecture gives an introduction in functional fabrication with focus on the nanoscale. As such, it discusses general deposition techniques but in particular those methods, which enable a controlled, localised structuring with feature sizes below 100 nm. X-Ray and Neutron Scattering: Basic principles of elastic and inelastic scattering techniques to study the structure and dynamics of materials at the atomic and molecular level.

	Research Laboratory Microscopy and Nanoanalysis: Practical training in the laboratory applying advanced experimental techniques related to current research topics in nanoscience.
Learning outcomes	After successfully completing this module, students are able to • understand the functionalities of electron microscopes and spectrometers for SEM and (S)TEM as well as other diffraction techniques. • interpret variations in image contrast, intensity and signal-to-noise ratio that result from electron specimen interactions. • understand diffraction effects and patterns and relate information to the crystallography of the specimen. • assess what microscopy and/or spectroscopy techniques in 2D or 3D are adequate for particular research and formulate a strategy for specimen preparation, microscopy observation and analysis. • use modern experimental equipment and methods of nanoscience. After having completed this module, students have • profound knowledge of microscopy and nanoanalysis techniques. • an insight into the potential of electron scattering and diffraction instruments. • specialised competence for material characterisation.
Teaching and learning activities and methods	Lectures, lectures with integrated exercises, laboratory courses
Recommended prerequisites for participation	Basic knowledge of Solid-State physics, experimental and computational techniques at a bachelor's degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Modelling of Materials**
ECTS credits	9
Contents	Students are introduced to modern simulation techniques for electronic and nuclear motion in atoms, molecules and bulk structures. They are trained to solve topical problems inspired by current research and industrial needs. ♦ Fundamentals of Electronic Structure Theory: Electronic band structure, free-electron bands and tight-binding approximation; SCF approximation; DFT; basis functions; full-potential and pseudopotential approach; advanced topics. ♦ Simulating Materials Properties from First Principles: Tutorial and scientific exercise; molecular properties, excitations, vibrations, visualisation, band-structure calculations, ab initio MD, interaction-driven Mott transition. Applications of Electronic Structure Methods: Interpretation of electronic structure calculations; global structure determination; ab initio thermodynamics; vibrations; phonon bands and heat transport; optical and core-level excitations; scanning probe experiments. Ab Initio Methods for Correlated Materials: Introduction to correlated materials; localised basis sets; Hubbard model and calculation of interaction parameters; (non-)Fermi liquids; dynamical mean field; Mott-Hubbard model. Advanced Electronic Structure Theory: Going beyond semi-local functionals; perturbative approaches beyond DFT – G0W0 and GW; dispersion corrections;

	RPA; the Bethe-Salpeter equation for simulating excitations; time-dependent DFT. Modelling of Molecular Systems: Non-Born-Oppenheimer effects; rovibronic interactions; group theory; excited states; post-Hartree-Fock techniques; solvation, QM/MM embedding; reaction dynamics and transition state theory.
Learning outcomes	The module provides students with a solid methodical and computational background as well as practical knowledge regarding programme packages and libraries at the cutting edge of current research. After successful completion, students are equipped with substantial knowledge in the field of materials modelling and electronic structure theory, which makes them valuable job candidates at materials research facilities.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Knowledge of quantum mechanics, electrodynamics, advanced quantum mechanics
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Nano and Laser Optics**
ECTS credits	9
Contents	♦ Optics – A Photonics Perspective: Light and matter; interference and diffraction; beam and pulse propagation; layered media and waveguides; microscopy; sources and detectors. ♦ Research Laboratory Nano and Laser Optics: Practical training in advanced experimental techniques with the opportunity to choose topics according to interests and lectures attended. Nano Optics: Super-resolution microscopy; near-field microscopy; quantum emitters; photonic crystals; plasmonics; metamaterials. Laser Physics: Emission and absorption; Einstein coefficients; laser theory and rate equations; optical resonators and modes; laser pulses; laser types; laser safety. Ultrafast Laser Physics: Introduction to state-of-the-art research field of femtosecond time-resolved molecular spectroscopy: generation and amplification of femtosecond laser pulses; pulse propagation in media, dispersion compensation; pulse characterisation; methods and examples of femtosecond time-resolved spectroscopy; strong field effects; applications.
Learning outcomes	After successfully completing this module, students are able to • understand and apply the concepts of ray and wave optics. • understand and apply the concepts of optical material properties and light-matter interaction at all length scales. • understand and apply the physical and technical principles of (ultrafast) lasers. After having completed this module, students have • the ability to design optical and laser setups.

	• the basis for a master's thesis in a research laboratory in the fields of modern optics and photonics.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Knowledge of experimental physics, quantum mechanics, electrodynamics and mathematical concepts at a bachelor's degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Nanoscience**
ECTS credits	9
Contents	♦ Nanostructures and Nanotechnology: Overview of physical nanoscience: physics of low-dimensional systems; electronic transport and magnetic properties on the nanoscale; nanoparticles, nanocrystalline and nanoporous materials; lateral nanostructuring; nanowires, nanotubes and nanodots; scanning probe techniques. ♦ Research Laboratory Nanoscience: Practical training in the laboratory with advanced experimental techniques related to current research topics of nanoscience. Chemical Fundamentals of Nanoscience: Chemical fundamentals of making nanoparticles; precipitation; sol-gel processes; dendrimers; supramolecular structures; carbon-based nanoparticles; toxicity of nanoparticles. Theory of Magnetism and Collective Phenomena: Magnetic exchange mechanisms; models for magnetic materials; response functions and phase transitions, Brown theory of micromagnetism; magnetic domains. Functional Nanofabrication: Overview of technologies that allow the defined fabrication of (functional) surface structures on the microscale and nanoscale. Theoretical Nano- and Quantum-Optics: Quantisation of the electromagnetic field, basic concepts of quantum optics; Green's function; optical near fields; surface plasmons.
Learning outcomes	After successfully completing this module, students are able to • understand the basic principles of low-dimensional systems and the methods of the interdisciplinary research field of nanoscience. • assess the relation between the structure and the properties of nanoscale materials. • use modern experimental equipment and methods of nanoscience. After having completed this module, students have • profound knowledge of nanoscience, allowing them to make use of specialist literature. • an insight into the application potentials of nanotechnology. • specialised competence in the field of one of the elective courses e.g., in the application of theoretical concepts in nanoscience.

Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Knowledge of Solid-State physics, quantum mechanics, experimental and computational techniques at a bachelor's degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Quantum Many-Body Physics**
ECTS credits	9
Contents	♦ <u>Quantum Theory of Many-Body Systems:</u> Correlation functions and linear response, Fermionic and Bosonic single-particle Green's functions, Perturbation theory and Feynman diagrams, Simple approximations: Hartree-Fock, Random Phase Approximation, Screening. <u>Introduction to Correlated Many-Body Systems:</u> Introduction to topical problems in strongly correlated many-body physics; models such as the Hubbard, Heisenberg, t-J and Kondo model are derived in second quantisation. In the framework of the Green's function formalism, electronic, magnetic, and optical properties are studied. <u>Many-Body Systems out of Equilibrium:</u> Non-equilibrium Green's functions and Keldysh contour; perturbation theory and diagrams; steady state; quantum transport; derivation of Boltzmann equations; impurity scattering; electron-electron and electron-phonon interactions; time-dependent phenomena. <u>Open Quantum Systems:</u> Classical master equation: time evolution of probabilities; reduced density matrix of an open system; elimination of degrees of freedom; Lindblad equation; microscopic derivation; solution methods; applications to quantum computer, decoherence and quantum measurement, quantum optics, quantum dots.
Learning outcomes	After successfully completing this module, students have • gained an overview of modern aspects of many-body physics. • acquired a deeper understanding of many-body quantum systems in and out of equilibrium, especially in connection with Solid-State physics. • learned several theoretical approaches to evaluate their properties, which are used for the research carried out at the area Theoretical and Computational Physics.
Teaching and learning activities and methods	Interactive classes with alternating lectures, tasks and exercises
Recommended prerequisites for participation	Knowledge of quantum mechanics at a master's degree level, elements of quantum statistics
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	Quantum Optics and Molecular Physics
ECTS credits	9
Contents	In this module, concepts of light-matter interaction are introduced and described with semiclassical and quantum physics. Topics ranging from light propagation in solids to femtosecond processes in isolated molecules are covered. ♦ Optics – A Spectroscopy Perspective: Basics of optics for research and industrial applications: light propagation in isotropic materials and birefringent crystals; polarisation optics; nonlinear optics; Fraunhofer and Fresnel diffraction, Fresnel zone plates; coherence and interference; Fourier optics. ♦ Research Laboratory Quantum Optics and Molecular Physics: Practical training in advanced experimental techniques with the opportunity to choose topics according to interests and lectures attended. Students also participate in one of the research experiments. Laser Physics: Emission and absorption; Einstein coefficients; laser theory and rate equations; optical resonators and modes; laser types; laser safety. Ultrafast Laser Physics: Introduction to state-of-the-art research field of femtosecond time-resolved molecular spectroscopy: generation and amplification of femtosecond laser pulses; pulse propagation in media, dispersion compensation; pulse characterisation; methods and examples of femtosecond time-resolved spectroscopy; strong field effects; applications. Quantum Optics: Correlated photons; theory of light-pressure force; laser cooling, trapped atomic ensembles; atom interferometry; quantum interference; atomic clocks, optical magnetometers (foundations and theory). Modelling of Molecular Systems: Non-Born-Oppenheimer effects; rovibronic interactions; group theory; excited states; post-Hartree-Fock techniques; solvation, QM/MM embedding; reaction dynamics and transition state theory.
Learning outcomes	After successfully completing this module, students are able to • solve optics-related tasks in research and industry, equipped with a substantial fundamental and practical basis. • understand light-induced molecular processes, their investigation with (femtosecond) laser radiation, as well as their modelling. • design and construct optical setups for laser applications. • carry out a master’s thesis in a research laboratory in the field of modern optics or laser spectroscopy.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Knowledge of experimental physics, quantum mechanics, electrodynamics and mathematical concepts at a bachelor’s degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	Radiation and Plasma Physics
ECTS credits	9

Contents	♦ Applied Radiation Physics: Introduction to ionising radiation sources, interaction of radiation with matter; human exposure to natural and man-made radiation sources, their biological effects, risks and tolerance limits; basics of dosimetry and activity measurements; applied radiation protection. ♦ Research Laboratory Radiation and Plasma Physics: Exercises on radiation detection, dosimetry and activity measurements, gamma-spectrometric identification of radionuclides and determination of radon concentration in air; computer simulations on topics of plasma or fusion physics. Plasma Physics: Collective effects in plasmas and conducting fluids; drift motions of charged particles in electromagnetic fields; plasma models; linear response of electric media; plasma waves. Fusion Physics: Introduction to nuclear fusion; magnetic confinement; inertial confinement; fusion concepts (tokamak, stellarator, mirror, field-reversed configuration) and related experiments; fusion fuels; power balance in fusion plasmas; technological aspects; safety aspects; comparison to nuclear fission; nuclear fusion in the sun and in stars (creation of elements in the universe). Kinetic Theory in Plasma Physics: Concepts of kinetic theory in plasma physics; comparison to single particle and fluid description; derivation of Liouville equation, Lenard-Balescu equation, Fokker-Planck equation and Vlasov equation; Coulomb collisions in plasmas; applications of kinetic theory.
Learning outcomes	After successfully completing this module, students are able to • understand the basic physical principles of ionising radiation, plasma and fusion processes. After having completed this module, students have • profound knowledge of ionising radiation and radiation protection. • an insight into the basic physics of ionised gases. • practical skills and specialised competence in radiation and plasma physics.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Introductory courses in theoretical mechanics and electrodynamics
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Semiconductor Devices**
ECTS credits	9
Contents	♦ Physics of Semiconductor Devices: Introduction to the band structures of semiconductors; intrinsic and extrinsic semiconductors; drift and diffusion of electrons and holes; p-n junctions; Schottky diodes; Ohmic contacts; JFETs,

	MESFETs; MOSFETs; CMOS; memories; bipolar transistors; solar cells; light-emitting diodes; laser diodes. ♦ Research Laboratory Semiconductor Devices: Characterisation of transistors; noise measurements; voltage-capacitance; the Hall effect; charge pumping; EBIC; EDMR; fabrication of organic devices; e-beam lithography; ellipsometry and pyrometry; SEM; TEM; FIB; IR spectroscopy; simulation laboratory. Microelectronics and Micromechanics: Basic processes of Si-planar technology; oxidation; thin film deposition; lithography; etching; fabrication of semiconductor devices; micromechanics; LIGA; micro-optics; microfluidics; EBID. Organic Semiconductors: Molecular and crystalline structures; liquid crystals; self-assembly processes; charge transport in organic semiconductors; photophysical and non-linear optical properties; organic light-emitting devices; lighting applications and displays; organic thin-film transistors; modelling of organic devices; fabrication of organic devices. Modelling and Simulation of Semiconductors: Introduction to the electronic structure of semiconductors; scattering mechanisms for electrons; transport modelling techniques (drift diffusion, Monte Carlo, Boltzmann equation); organic and nanotube field-effect transistors.
Learning outcomes	After successfully completing this module, students are able to • describe the fabrication and operation of semiconductor devices. • understand how the choice of materials changes the properties of the devices. • use modern experimental equipment and methods for the characterisation of semiconducting materials and devices.
Teaching and learning activities and methods	Lectures, laboratory exercises, independent project
Recommended prerequisites for participation	Knowledge of Solid-State physics, electrodynamics, computer programming, and experimental physics at a bachelor's degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Surface Science**
ECTS credits	9
Contents	♦ Surface Science: Geometric and electronic structure of surfaces (theory and methods); adsorption (thermodynamics, growth processes). ♦ Research Laboratory Surface Science: The focus is on understanding the principles of modern experimental surface science techniques and gaining direct hands-on experience with the techniques available at the surface science groups at Uni Graz and TU Graz. Introductory experiments (surface cleaning, structure and composition analysis, adsorption and desorption) are followed by a small research project on a specific instrument and topic. Molecular Interfaces: Bonding; orbitals; band structure; interfaces; angle-

	resolved UPS; orbital tomography. Scanning Probe Techniques: Scanning tunnelling microscopy (theory, operation, measurement modes, spectroscopy, applications, spin-polarised STM, inelastic STM/STS, manipulation); atomic force microscopy (theory, interaction forces, modes (static, dynamic), force-distance curves, Kelvin probe, magnetic force); spectro-microscopy: PEEM, LEEM, µ-XPS. Synchrotron Radiation Techniques: Synchrotron light generation (history, accelerators, etc.); synchrotron XPS (time-resolved, data analysis, line shapes, curve fitting, etc.); X-ray absorption spectroscopy (EXAFS, XANES). Thin Film Science and Processing: Principles of thin film growth, thermodynamics and kinetics, adsorption, desorption, diffusion, techniques (PVD, CVD, LB, spin coating), nanostructure fabrication (etching, etc.). Surface Chemistry: Chemical reactions on surfaces (heterogeneous catalysis; photocatalysis; electrochemistry). Vacuum Technology: Gas kinetics, pumps, pressure measurements, vacuum chambers, safety.
Learning outcomes	After successfully completing this module, students are able to • understand the fundamental (geometric and electronic) properties of surfaces as a representation of a truncated crystalline bulk material. • understand the principles, operate and interpret the results obtained with state-of-the-art ultra-high vacuum-based surface science methods and standard surface analytical methods for industry. • understand the principles and methods of adsorption on surfaces, self-assembly, thin film growth and nanostructuring. The optional courses provide students with more in-depth knowledge of the systems and techniques of surface physics and surface chemistry.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Knowledge of Solid-State physics
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Theoretical Solid-State Physics**
ECTS credits	9
Contents	Quantum Theory of Many-Body Systems: Correlation functions and linear response, Fermionic and Bosonic single-particle Green's functions, Perturbation theory and Feynman diagrams, Simple approximations: Hartree-Fock, Random Phase Approximation, Screening. Fundamentals of Electronic Structure Theory: Electronic band structure, free-electron bands and tight-binding approximation; self-consistent field approximation; density functional theory; basis functions; full-potential and pseudopotential methods; advanced topics. Theory of Magnetism and Collective Phenomena: Magnetic exchange mechanisms; models for magnetic materials; response functions and phase transitions; Brown theory of micro-magnetism; magnetic domains.

	Theory of Superconductivity: Phenomenology of superconductors; the Meissner effect; London equations; microscopic theory: BCS theory at zero and finite temperatures; introduction to strong-coupling Migdal-Eliashberg theory. Phase Transitions and Critical Phenomena: Lattice models and applications of statistical physics; mean field, perturbation series, transfer matrix, renormalisation group, mapping between representations; simulation techniques and examples, including cluster Monte Carlo and Kosterlitz-Thouless transition.
Learning outcomes	After successfully completing this module, students have a clear overview of the fundamental methods and open problems of modern theoretical Solid-State physics. They have acquired the basic skills to solve related problems at the level of a master's thesis.
Teaching and learning activities and methods	Lectures with multimedia material
Recommended prerequisites for participation	Knowledge of Solid-State physics, quantum mechanics and statistical physics at a master's degree level
Frequency in which the module is provided	Mandatory courses (♦) every year; others at least every two years

Specialization Module:	**Photon Science**
ECTS credits	9
Contents	Research Laboratory Photon Science: Practical training in advanced experimental optical techniques with a selection of intriguing topics related to photon sciences to be chosen in accordance with interests and lectures attended. Laser Spectroscopy: Laser spectroscopy techniques for atomic and molecular gases, liquids, and solids; overview on optical spectroscopic diagnostic instrumentation; high-frequency and time-resolved spectroscopy and related diagnostic methods including most recent developments in optical spectroscopy, ranging from the X-ray to the infrared spectral region. Structured Light and Nanoscale Wave Phenomena: Introduction to the fascinating structure of light – from tall to small; discussion of various types of structured electromagnetic fields, generation methods and inherent properties; evanescent and propagating fields, polarisation, angular momenta of light fields, optics of dielectric and metallic nanostructures, light-matter interactions at the nanoscale; exotic phenomena and intriguing effects in nanostructured fields; modern applications in nano-metrology, sensing, imaging, spectroscopy, polarimetry, photonic nanocircuitry, etc. Photonics: Light, Matter, and Time: Ultrafast time-domain perspective on optical properties of atoms and solids, dynamics of energy exchange between electric field and matter; refractive index and transition rates from quantum mechanical principles, optical control of charge and spin. Optical Waveguides, Photonic Circuitry and Applications: Introduction to various kinds of optical waveguides (integrated, dielectric, plasmonic, photonic crystal waveguides and fibres); discussion of photonic integrated circuits, corresponding components, and fascinating applications as well as recent developments.

	<u>Optical Measurement Techniques</u>: Introduction to optical spectroscopy methods for physics, chemistry and biological sciences with focus on providing knowledge for estimating applicability ranges of various methods, and on basics of spectroscopy instruments.
Learning outcomes	After successfully completing this module, students have • a concise theoretical knowledge base in photon science and related areas of physics (Optics, Electrodynamics, Quantum Mechanics, Physics of Semiconductors). • an understanding of fundamental laws of physics driving modern engineering areas including telecommunications, optoelectronics, photonics, nano- and microfabrication. • essential laboratory skills including experimental design, assembly of optical equipment, data acquisition and analysis. • training to communicate scientific and engineering ideas both orally and in written form.
Teaching and learning activities and methods	Lectures, laboratory courses
Recommended prerequisites for participation	Fundamentals of electrodynamics and optics as well as corresponding mathematical concepts at a bachelor's degree level
Frequency in which the module is provided	Every year

Appendix II Recommended Curriculum Timeline

1st semester	SSt.	Type	ECTS	Uni Graz[1]	TU Graz[1]
Statistical Physics	2	VO	4	X	X
Statistical Physics	1	UE	2	X	X
Advanced Quantum Mechanics	2	VO	4	X	X
Advanced Quantum Mechanics	1	UE	2	X	X
Advanced Solid-State Physics	3	VO	6	X	X
Elective modules			9	X	X
Free Electives			3	X	X
1st semester total			30		
2nd semester					
Computer Simulations	3	VU	4		X
Advanced Atomic and Molecular Physics	2	VO	4		X
Radiation Physics	2	VO	4		X
Compulsory Module Business and Entrepreneurship			4.5		X
Elective modules			9	X	X
Free Electives			4.5	X	X
2nd semester total			30		
3rd semester					
Elective modules			24	X	X
Free Electives			3	X	X
3rd semester total			27		
4th semester					
Master’s seminar	2	SE	2	X	X
Master’s thesis			30	X	X
Master’s examination			1	X	X
4th semester total			33		
Total overall ECTS			120		

[1]: Assignment of the course to the participating universities. Both universities are named if the course is offered at both universities in combination, in parallel or alternately.

Appendix III Recommended Courses for the Free Electives

Free-elective courses can be freely chosen from the courses offered at any recognized Austrian and foreign universities, and Austrian universities of applied sciences and university colleges for education according to § 10 of this curriculum.

For students to broaden their knowledge in subjects relevant to the modules of this degree programme, courses in the fields of foreign languages, social competence, technological impacts assessment and women's and gender studies (especially the lecture “A doctoral programme at the Faculty of Mathematics, Physics and Geodesy – Information event for female master's students”) are recommended. In particular, we would like to refer students to the courses offered by the TU Graz service department Languages, Key Competencies and In-House Training or at Treffpunkt Sprachen of the Uni Graz, the Centre for Social Competence of Uni Graz, the transfer initiative for management and entrepreneurship fundamentals ("TIMEGATE") of the Uni Graz as well as the Inter-University Research Centre for Technology, Work and Culture (IFZ). The interdisciplinary master's degree modules “Master's Degree Plus” offered by the University of Graz are recommended in addition to the above.

As part of the Free Electives, students can complete an exclusive tutorial worth 2 ECTS credits, which is offered by the master's thesis supervisor with a teaching qualification.

Other recommended courses for Free Electives:							
Course		Course		Semester		Uni Graz[1]	TU Graz[1]
	SSt.	**Type**	**ECTS**	**WS**	**SS**		
Praxiseinblick: Human Ressource Management[1]	1	KS	1	X	X	X	

[1]: This course is held in German.

Appendix IV Equivalence List

Courses whose equivalence or recognition is defined in this appendix to the curriculum no longer require individual recognition by the dean of studies. However, an individual recognition of a course is possible in accordance with § 78 Universities Act 2002 (UG). An equivalence list defines the equivalence of positively completed courses from this present curriculum and the previous curriculum. This equivalence is valid in both directions, i.e., positively completed courses of the previous curriculum are recognized under the current curriculum and positively completed courses of the current curriculum are recognized under the previous curriculum.
Courses that have the same title and are of the same type and have the same number of ECTS credits or the same number of semester hours, are equivalent per se and are not listed in the equivalence list.

Previous curriculum for 2017				**can be replaced by courses from the current curriculum 2023**			
Course	**Type**	**SSt.**	**ECTS**	**Course**	**Type**	**SSt.**	**ECTS**
Compulsory Module							
Advanced Solid-State Physics *and* Advanced Solid-State Physics	VO *and* UE	2 *and* 1	4 *and* 2	Advanced Solid-State Physics	VO	3	6
Specialization Module I (Modelling of Materials)							
Advanced Ab-Initio Techniques	VO	2	3	Advanced Electronic Structure Theory	VO	2	3
Specialization Module J (Nano- and Laser-Optics)							
Advanced Optics	VO	2	3	Optics – A Photonics Perspective	VO	2	3
Specialization Module L (Quantum Many-Body Systems)							
Green's Function in Many-Particle Physics	VU	2	3	Quantum Theory of Many-Body Systems	VU	2	3
Specialization Module K (Nanoscience)							
Quantum Transport Theory	VO	2	3	Theoretical Nano- and Quantum-Optics	VO	2	3
Specialization Module M (Quantum Optics and Molecular Physics)							
Fundamental Optics	VO	2	3	Optics – A Spectroscopy Perspective	VO	2	3
Specialization Module P (Surface Science)							
Experimental Methods in Surface Science	VU	2	2	Research Laboratory Surface Science	LU	2	3
Specialization Module Q (Theoretical Solid-State Physics)							
Green's Function for Solid-State Physics	VU	2	3	Quantum Theory of Many-Body Systems	VU	2	3
Elective Topics							

Programming in Physics: Advanced MATLAB	VU	4	4	Software Engineering in Physics	VU	4	4

If students have already successfully completed “Green's Functions for Solid-State Physics” and “Green's Functions in Many-Particle Physics” for the 2017 version of the curriculum, these courses can be recognized for Modules L and Q. Courses from the previous curriculum version that have already been completed but are not included in any of the modules or in the equivalence list of the new curriculum can still be recognized for the module in which they originally appeared.

Appendix V Glossary

Glossary of the terms used that differently in the statutes and guidelines of the two universities:

Term used in this curriculum (NAWI GRAZ)	**Uni Graz terminology**	**TU Graz terminology**
SSt.	KStd.	SSt.
Elective Topics		Wahlfach
Free Electives	Freie Wahlfächer	Freie wählbare Lehrveranstaltung