# **Modules and Courses**

# **Excellence Track**

3. April 2024

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# 1 List of Modules and Courses

## 1.1 Overview of the Modules

Module	SWS	CP
soft skills		
Speak your science	$4 \mathrm{V}$	3
DPG spring meetings and other conferences		3
Complementary Skills workshops of different suppliers		1
to choose		6-9
physics courses		
Topical Courses	$3 \mathrm{V} + 1 \mathrm{\ddot{U}}$	6
Advanced Courses	$3 \mathrm{V} + 1 \mathrm{\ddot{U}}$	6
Laboratory project	4 P	5
to choose		14 - 17
Total		23

## 1.2 List of Topical Courses

- Condensed Matter Physics
  - Selected Topics in Condensed Matter Physics
  - Modern Experimental Methods in Condensed Matter Physics
  - Materials Science
  - Introduction to Advanced Materials from soft matter to hard matter
  - Quantum Spintronics
  - Superconductivity
  - Nonequilibrium phenomena in quantum matter
  - Introduction to Condensed Matter Theory
  - Selected Chapters of Condensed Matter Theory
  - Theory of Soft Matter I
  - Modern Computational Techniques in Condensed/Soft Matter Physics
  - Computer Simulations in Statistical Physics
  - Soft Materials at Interfaces
  - Biophysics
  - Advanced theoretical solid state physics
- Quantum, Atomic and Neutron Physics
  - Quantum Optics (Q-Ex-1)
  - Photonics (Q-Ex-2)
  - Quantum Information (Q-Ex-3)
  - Precision Fundamental Physics (Q-Ex-4)
- Nuclear and Particle Physics
  - Statistics, Data Analysis and Simulation
  - Particle Detectors
  - Accelerator Physics
  - Particle Physics
  - Astroparticle Physics
  - Cosmology and General Relativity
  - Symmetries in Physics
  - Modern Methods in Theoretical High Energy, Particle and Nuclear Physics
  - Theoretical Particle Physics
  - Theoretical Nuclear Physics
  - Introduction to Lattice Gauge Theory
  - Introduction to String Theory
  - Effective Field Theories
  - Theoretical Astroparticle Physics
  - Amplitudes and Precision Physics at the LHC
  - Functional Methods and Exact Renormalization Group

## 1.3 List of Advanced Courses

- Condensed Matter Physics
  - Theory of Soft Matter II
- Nuclear and Particle Physics
  - Advanced Particle Physics
  - Advanced Chapters on Subatomic Physics
  - Advanced Astroparticle- and Astrophysics
  - Advanced Accelerator Physics

# **2 Important Remarks**

The certificate program "Excellence Track (Physics)" is aimed at high-achieving, research-oriented students. It enables them to develop their scientific knowledge and skills as well as complementary skills beyond the normal offers and requirements within the framework of their regular Master's program at JGU. The aim is on the one hand to introduce the students to current research at an early stage and to integrate them into the working groups and on the other hand to enable the students to acquire additional scientific knowledge (Scientific Knowledge) and Complementary and Transferable Skills in a structured program. For successful participation in the Excellence Track, students enrolled for it must acquire 23 additional credit points in addition to their regular Master's program. These must be earned before submitting the master's thesis and are distributed across two pillars:

- 1. Research-related scientific competence (subject knowledge) in the field of physics with at least 14 CP. as well as
- 2. Complementary Skills with at least 6 CP.

All other regulations from "Modules and courses" for the M.Sc. Physics apply.

## 3.1 Soft skills

	Module EK: Speak your science 08.128.619					8.619	
Compulsory or elective module	W						
Credit points and workload	3 LP = 90 h						
<b>Duration</b> according to the study plan	1						
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points	
Speak your science		1	W	4 SWS	58,5 h	3 LP	
To complete the module, the follow	ving a	chievements mus	t be made:			1	
Presence							
Active participation							
Course achievements							
Module examination							
Qualification and program goals /	Comp	etences					
communication. During the course participants will work on short presentations which they will improve along the way. Regular participation at the Physics Colloquium and critical assessment of the talks via evaluation forms will provide self-reflection. Along with theatre and story, the use of slides, addressing different audiences and reacting to questions are also part of the course.  Course content Identify key messages to bring across, grab and hold the audience's attention, the art of storytelling, body-language							
Identify key messages to bring across, gra				•		liences and	
Identify key messages to bring across, gra communication, structure of a presentat				•		liences and	
Identify key messages to bring across, gra communication, structure of a presentat Entry requirements				•		liences and	
Identify key messages to bring across, gra communication, structure of a presentat			n, getting bet	•	ng others	liences and	
Identify key messages to bring across, gra communication, structure of a presentat Entry requirements Recommended prerequisites	ion, sty	'le of a presentatio	n, getting bet Course lang Examinatio	ter at readinguage Englis	ng others h English	liences and	
Identify key messages to bring across, gra communication, structure of a presentat Entry requirements Recommended prerequisites Language	ion, sty	'le of a presentatio	n, getting bet Course lang Examinatio	guage Englis on language 1 ) or 3/120 (1	ng others h English	liences and	
Identify key messages to bring across, gra communication, structure of a presentat Entry requirements Recommended prerequisites Language Weighting of the achievement in the	ion, sty	'le of a presentatio	n, getting bet Course lang Examinatic 3/180 (BSc	guage Englis on language 1 ) or 3/120 (1	ng others h English	liences and	
Identify key messages to bring across, gra communication, structure of a presentat Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	ion, sty ne over	'le of a presentatio	n, getting bet Course lang Examinatic 3/180 (BSc	guage Englis on language 1 ) or 3/120 (1 er semester	ng others h English	liences and	
Identify key messages to bring across, gra communication, structure of a presentat Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	ion, sty e over	'le of a presentatio	n, getting bet Course lang Examinatio 3/180 (BSc Every wint Prof. Dr. C	guage Englis on language 1 ) or 3/120 (1 er semester	ng others h English MSc)	liences and	

	DPG spring meetings and other confe- rences 08.128.ET000					
Compulsory or elective module	P					
Credit points and workload	3 LP = 90 h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit
	pe	term	obligation	$\mathbf{time}$	study	points
Conference		1	Р			3 LP
To complete the module, the follow	ving a	chievements mus	st be made:		1	1
Presence						
Active participation						
Course achievements						
Module examination	Prese	entation within the	conference			
Qualification and program goals /	Comp	etences				
Current topics in physics, which forms the basis for the student's own research project as part of the master' thesis. Learning presentation techniques and testing them in front of a scientific audience. Preparation of slide						
and presentation in English if necessary.		esting them in from		fic audience.		
		esting them in from		fic audience.		
and presentation in English if necessary.		-		fic audience.		
and presentation in English if necessary. Course content		-		fic audience.		
and presentation in English if necessary. Course content Student talk about the student's own re		-		fic audience.		
and presentation in English if necessary. Course content Student talk about the student's own re Entry requirements		-	t of a scienti	fic audience. guage Englis on language I	Preparat.	
and presentation in English if necessary. Course content Student talk about the student's own re Entry requirements Recommended prerequisites	search	project	t of a scienti	guage Englis	Preparat.	
and presentation in English if necessary. Course content Student talk about the student's own re Entry requirements Recommended prerequisites Language	search	project	t of a scienti	guage Englis	Preparat.	
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and presentation in English if necessary. Course content Student talk about the student's own re Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	search ne over	project	t of a scienti	guage Englis on language l Anbieter	Preparat.	
and presentation in English if necessary. Course content Student talk about the student's own re- Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	search ne over e e	project	t of a scienti Course lang Examinatic	guage Englis on language l Anbieter	Preparat.	ion of slides

Modul ET001	Complementary Skills workshops of dif- ferent suppliers					28.ET001	
Compulsory or elective module	Р						
Credit points and workload	1  LP = 30  h						
<b>Duration</b> according to the study plan	1						
	Ty-	Designated	Degree of	Contact	Self	Credit	
Courses and teaching methods	pe	term	obligation	$\operatorname{time}$	study	points	
Workshop		1	Р	min 14 h		1 LP	
To complete the module, the follow	ving ad	chievements mus	t be made:				
Presence							
Active participation							
Course achievements							
Module examination	majo	examination is req r course content n e upon successful c	nust be subr	nitted to the			
Qualification and program goals /	Comp	etences					
Acquisition of Complementary Skills							
Course content							
See course descriptions of suppliers such	as IM	B, "General Postgr	aduate Prog	ram", etc.			
Entry requirements			sible, via the MPA. The MPA Coordinati- on Office must be notified in writing by the end of the first week of the semester if cour- ses from the complementary skills area are to be taken. Upon successful completion of the- se courses, copies of the certificates of atten- dance must be submitted to the Coordination Office.				
Recommended prerequisites			Depending on the provider, registration in person via the provider's platform or, if pos- sible, via the MPA. The MPA Coordinati- on Office must be notified in writing by the end of the first week of the semester if cour- ses from the complementary skills area are to be taken. Upon successful completion of the- se courses, copies of the certificates of atten- dance must be submitted to the Coordination Office.				
Language			Course language English Examination language English				
Weighting of the achievement in th	le over	all grade		10011800080 1	0		
Module frequency		0					
Reasons for compulsory attendance	<u>р</u>						
Persons responsible for this module			Jeweilige Anbieter der Veranstaltung bzw. deren Referenten				
Applicable to the following program	ns			Track (Physi	.cs)		
Miscellaneous							

# 3.2 Laboratory project

	Laboratory project					8.128.ET002
Compulsory or elective module	Р					
Credit points and workload	5  LP = 150  h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	$\mathbf{time}$	study	points
Laboratory project (P)	Pr	2	Р	4 SWS	108 h	5 LP
To complete the module, the follow	ving a	chievements mu	st be made:			
Presence						
Active participation						
Course achievements						
Module examination	Repo	ort				
The students are supposed to deepen ad This is practiced by carrying out challen supervision of experienced assistants. U methods are used.	ging ex	periments in two-p	person teams,	extending o	ver several	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental	ging ex Jsually	periments in two-p complex data acc	person teams, quisition syste	extending or ems and cor	ver several	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature	ging ex Jsually or the	complex data acc	person teams, quisition syste	extending or ems and cor	ver several	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe	ging ex Jsually or the	complex data acc	person teams, quisition syste	extending or ems and cor	ver several	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe Entry requirements	ging ex Jsually or the	complex data acc	person teams, quisition syste	extending or ems and cor	ver several	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe	ging ex Jsually or the	complex data acc	person teams, quisition syste p has to be po	extending or ems and cor erformed.	ver several nputer-bas	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe Entry requirements Recommended prerequisites Language	ging ex Jsually or the erences	complex data acc oretical work grou	person teams, quisition syste p has to be pe Course lang Examinatio	extending or ems and cor	ver several nputer-bas	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe Entry requirements Recommended prerequisites	ging ex Jsually or the erences	complex data acc oretical work grou	person teams, quisition system p has to be per Course lang Examination 5/23	extending or ems and cor erformed. guage Germa on language	ver several nputer-bas	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	ging ex Jsually or the erences	complex data acc oretical work grou	person teams, quisition syste p has to be pe Course lang Examinatio	extending or ems and cor erformed. guage Germa on language	ver several nputer-bas	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	ging ex Jsually or the erences	complex data acc oretical work grou	person teams, quisition system p has to be person Course lang Examination 5/23 Every seme	extending o ems and cor erformed. guage Germa on language ester	ver several nputer-bas	l days under
This is practiced by carrying out challen, supervision of experienced assistants. U methods are used. Course content An extended project in an experimental Literature Manuals of experiments with special refe Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance Persons responsible for this module	ging ex Jsually or the erences	complex data acc oretical work grou	person teams, quisition system p has to be por Course lang Examination 5/23 Every seme Prof. Dr. W	extending or ems and cor erformed. guage Germa on language ester	ver several nputer-bas an German	l days under
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## 3.3 Topical and Advanced Courses

## 3.3.1 Condensed Matter Physics

	Module Topical Courses: "Selected to- pics in Condensed Matter Physics"08.128.720						
	Proz			-9.2200			
Compulsory or elective module	WP						
Credit points and workload	6 LP = 180 h						
<b>Duration</b> according to the study plan	1       Ty-     Designated     Degree of     Contact     Self     Credit						
Courses and teaching methods	Ty-         Designated         Degree of         Contact         Self						
Courses and reaching methods	ре	term	obligation	time	study	points	
Lecture with excercises "Selected topics		1	Р		138 h	6 LP	
in Condensed Matter Physics" (WP)		L	I		130 11	0 11	
Lecture (WP)	V			$3 \ \mathrm{SWS}$			
Excercises (WP)	Ü			$1 \ \mathrm{SWS}$			
To complete the module, the follow	ving a	chievements mus	t be made:				
Presence							
Active participation	accor	ding to §5 subsect	ion 3				
Course achievements	succe	essful completion of	exercises or	projects			
Module examination	Writt	ten exam (120-180	Min.), oral e	xamination (	(30 Min.),	term paper	
	or pr	esentation					
Qualification and program goals /	Comp	etences					
correlated dynamics of electrons in solids and provide the basis of modern electronics and information technology. Surface Science is essential for an in depth understanding of miniaturized devices as well as for novel diagnostic techniques. Soft Matter shows fascinating structural and dynamic properties and nurtures a rapidly developing field of applications. Its fundamental scientific questions also related to other disciplines like biology, chemistry and medicine. By an depth treatment of one or more of these topics, the course will provide a solid basis for conducting a master thesis in the area of Condensed Matter Physics.							
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we	entific of one f Cond ill focu	questions also relator more of these then the set of th	ted to other opics, the co ics.	disciplines l urse will pro	ike biology ovide a sol	y developing y, chemistry lid basis for	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur	entific of one f Cond ill focu	questions also relator more of these then the set of th	ted to other opics, the co ics.	disciplines l urse will pro	ike biology ovide a sol	y developing y, chemistry lid basis for	
field of applications. Its fundamental sci and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b>	entific of one f Cond ill focu	questions also relator more of these then the set of th	ted to other opics, the co ics.	disciplines l urse will pro	ike biology ovide a sol	y developing y, chemistry lid basis for	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer	entific of one f Cond ill focu	questions also relator more of these then the set of th	ted to other opics, the co ics.	disciplines l urse will pro	ike biology ovide a sol	y developing y, chemistry lid basis for	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer <b>Entry requirements</b>	entific of one f Cond ill focu	questions also relator more of these then the set of th	ted to other opics, the co ics.	disciplines l urse will pro	ike biology ovide a sol	y developing y, chemistry lid basis for	
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field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer <b>Entry requirements</b>	entific of one f Cond ill focu	questions also relator more of these then the set of th	ted to other opics, the co ics. , such as mag r physics Course lang	disciplines l urse will pro	ike biology ovide a sol er conduct h	v developing y, chemistry lid basis for 	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer <b>Entry requirements</b> <b>Recommended prerequisites</b>	entific of one f Cond ill focu face sc	questions also rela or more of these t ensed Matter Phys s on specific topics ience or soft matter	ted to other opics, the co ics. , such as mag r physics Course lang	disciplines l urse will pro gnetism, supe guage Englis	ike biology ovide a sol er conduct h	v developing y, chemistry lid basis for 	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur Literature will be provided by the lecturer Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	entific of one f Cond ill focu face sc face sc	questions also rela or more of these t ensed Matter Phys s on specific topics ience or soft matter	course lang Examinatio 6/120	disciplines l urse will pro gnetism, supe guage Englis	ike biology ovide a sol er conduct h	v developing y, chemistry lid basis for 	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer <b>Entry requirements</b> <b>Recommended prerequisites</b> <b>Language</b> Weighting of the achievement in the	entific of one f Cond ill focu face sc face sc	questions also rela or more of these t ensed Matter Phys s on specific topics ience or soft matter	course lang Examinatio 6/120	disciplines l urse will pro metism, supe guage Englis on language	ike biology ovide a sol er conduct h	v developing y, chemistry lid basis for 	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer <b>Entry requirements</b> <b>Recommended prerequisites</b> <b>Language</b> Weighting of the achievement in the Module frequency	entific of one f Cond ill focu face sc e over	questions also rela or more of these t ensed Matter Phys s on specific topics ience or soft matter	ted to other opics, the co ics. , such as mag r physics Course lang Examinatic 6/120 Each summ	disciplines l urse will pro metism, supe guage Englis on language	ike biology ovide a sol er conduct h English or	developing y, chemistry lid basis for ivity, heavy German	
field of applications. Its fundamental set and medicine. By an depth treatment of conducting a master thesis in the area of <b>Course content</b> Depending on the lecturer, the course we fermions, applied solid state physics, sur <b>Literature</b> will be provided by the lecturer <b>Entry requirements</b> <b>Recommended prerequisites</b> <b>Language</b> Weighting of the achievement in the Module frequency <b>Reasons for compulsory attendance</b>	entific of one f Cond ill focu face sc e e e	questions also rela or more of these t ensed Matter Phys s on specific topics ience or soft matter	ted to other opics, the co ics. , such as mag r physics Course lang Examinatic 6/120 Each summ	disciplines l urse will pro gnetism, supe guage Englis on language f her semester c. Palberg, P	ike biology ovide a sol er conduct h English or	developing y, chemistry lid basis for ivity, heavy German	

	Module Topical Courses: " Modern Ex- perimental Methods in Condensed Mat- ter Physics"08.128.721					28.721
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Modern Expe- rimental Methods in Condensed Matter Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \ \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination	1	ten exam (120-180 esentation	Min.), oral ex	xamination	(30 Min.),	term paper
Qualification and program goals /	Comp	etences				
Students shall be guided towards both fundamental facts and special aspects of state-of-the-art experimental methods in material science. The course will therefore present important and state of the art techniques and approaches. Examples may include spectroscopic methods, scattering techniques, scanning probe techniques as well as application related characterization of novel materials, sample preparation and conditioning techniques. Dealing with one or more of such topics, the course will develop an enhanced understanding of a research related area of expertise in Condensed Matter Physics. It will further provide a solid basis for conducting a master thesis						xperimental
methods in material science. The course approaches. Examples may include spec- well as application related characterizati Dealing with one or more of such topics, area of expertise in Condensed Matter P	e will troscoption of the control hysics.	therefore present i pic methods, scatte novel materials, sa urse will develop a It will further prov	mportant and ering techniqu mple prepara n enhanced u	d state of the ues, scanning tion and con- nderstanding	ne art tech g probe te nditioning g of a resea	niques and chniques as techniques. arch related
methods in material science. The course approaches. Examples may include spec- well as application related characterization Dealing with one or more of such topics,	e will troscoption of the control hysics.	therefore present i pic methods, scatte novel materials, sa urse will develop a It will further prov	mportant and ering techniqu mple prepara n enhanced u	d state of the ues, scanning tion and con- nderstanding	ne art tech g probe te nditioning g of a resea	niques and chniques as techniques. arch related
methods in material science. The course approaches. Examples may include spec- well as application related characterization Dealing with one or more of such topics, area of expertise in Condensed Matter Pa- in Condensed Matter Physics in this or a	e will troscop ion of the co hysics. a relate will fo ues, sca	therefore present i pic methods, scatte novel materials, sa urse will develop a It will further pro- ed area.	mportant and ering technique mple prepara n enhanced u vide a solid ba	d state of the ues, scannin, tion and con- nderstandin asis for cond spectroscopi sis strategie	ne art tech g probe te nditioning g of a rese ucting a m c methods	arch related aster thesis
methods in material science. The course approaches. Examples may include spec- well as application related characterizati Dealing with one or more of such topics, area of expertise in Condensed Matter P in Condensed Matter Physics in this or a <b>Course content</b> Depending on the lecturers, the course techniques, modern microscopy technique	e will troscop ion of the co hysics. a relate will fo ues, sca	therefore present i pic methods, scatte novel materials, sa urse will develop a It will further pro- ed area.	mportant and ering technique mple prepara n enhanced u vide a solid ba	d state of the ues, scannin, tion and con- nderstandin asis for cond spectroscopi sis strategie	ne art tech g probe te nditioning g of a rese ucting a m c methods	iniques and chniques as techniques. arch related haster thesis
methods in material science. The course approaches. Examples may include spect well as application related characterization Dealing with one or more of such topics, area of expertise in Condensed Matter P in Condensed Matter Physics in this or a <b>Course content</b> Depending on the lecturers, the course techniques, modern microscopy technique techniques or methods for material characterial	e will troscop ion of the co hysics. a relate will fo ues, sca	therefore present i pic methods, scatte novel materials, sa urse will develop a It will further pro- ed area.	mportant and ering technique mple prepara n enhanced u vide a solid ba	d state of the ues, scannin, tion and con- nderstandin asis for cond spectroscopi sis strategie	ne art tech g probe te nditioning g of a rese ucting a m c methods	iniques and chniques as techniques. arch related haster thesis
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Modul 722		lule Topical ( nce"	Courses: "	Materia	ls 08.12	8.722
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	$\mathbf{time}$	study	points
Lecture with excercises "Materials Science" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	t be made:		•	-1
Presence						
Active participation	accor	ding to §5 subsecti	on 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination	Writt	en exam (120-180	Min.), oral e	xamination (	30 Min.),	term paper
	or pr	esentation				
Qualification and program goals $/$	Comp	etences				
Students shall be guided towards the essential physics of Material Science that is necessary for an understanding of processes in novel materials on the atomic and the nano-scale. Topics of interest covered by the course are, for example, the structure and properties of functional materials, nanomaterials, fluids and soft materials, glasses, functionalized surfaces, formation of and transitions within solids, modern methods of material science, as well as concepts and fundamentals of novel materials including their development and application. Dealing with one or more of such topics, the course will develop an enhanced understanding of a research related area of expertise in Condensed Matter Physics. It will further provide a solid basis for conducting a master thesis in Condensed						
example, the structure and properties of functionalized surfaces, formation of and as concepts and fundamentals of novel r or more of such topics, the course will de in Condensed Matter Physics. It will fu	f funct d trans nateria evelop	ional materials, na itions within solids ls including their o an enhanced under	nomaterials, s, modern me levelopment a standing of a	rest covered fluids and sethods of ma and applicat research rel	by the cou oft material terial sciention. Dealin ated area	urse are, for als, glasses, nce, as well ng with one of expertise
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Modul AdvMat	Modul Spezialvorlesungen: "Introducti- on to Advanced Materials - from soft matter to hard matter" Module Topical Courses: "Introduction to Advanced Materials - from soft matter to hard matter"08.128.7012						
Compulsory or elective module	WP						
Credit points and workload	6 LP = 180 h						
<b>Duration</b> according to the study plan	1						
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points	
Vorlesung mit Übung "Introduction to Advanced Materials - from soft matter to hard matter" (WP) Vorlesung	V	1 (2)	WP	3 SWS	138 h	6 LP	
Übung	Ü			1 SWS			
To complete the module, the follow	ing a	chievements mus	st be made:				
Presence		0.05 41 0					
Active participation	-	ß §5 Abs. 3	-11-		1/ 1 -		
Course achievements		greiche Bearbeitun		0	,	*	
Module examination		sur (Umfang 120 lliche Prüfung (30					
Qualification and program goals /	Comp	etences					
sowie die Wechselwirkungsenergie der at die Materialeigenschaften bestimmt. Als zur Untersuchung von harter, als auch v Einführung in die Rheologie. An einem ein forschungsnahes Spezialgebiet der ko Masterarbeit erfolgreich durchführen zu <b>Course content</b>	univer on wei oder a ondens: könner	rselle Analysemeth cher Materie eigne n mehreren spezie ierten Materie ents 1.	ode wird Str tt. Für die we llen Themen stehen, das e	euung eingef eiche Materie soll ein vert	ührt, was a e erfolgt ük ieftes Vers	sich sowohl berdies eine tändnis für	
<ul> <li>Einführung in Kristallstrukturen, Git</li> <li>Einführung in weiche Materie inklusif</li> <li>Einführung in Streuung mit Photonen und magnetischen Systemen</li> <li>Einführung in die Rheologie von Poly</li> <li>Einführung in den Magnetismus</li> </ul>	ve Poly , Neutr	vmere		suchung von	Kristallen,	Polymeren	
Literature							
C. Kittel: Einführung in die Festkörperph M. Rubinstein & R. H. Colby: Polymer	•	-				sed Matter,	
Entry requirements							
Recommended prerequisites							
Language				sprache Eng rache Deutse		glisch	
Weighting of the achievement in th	e over	rall grade	6/120				
Module frequency			In der Rege	el jährlich			
Reasons for compulsory attendance	e			-			
Persons responsible for this module			Prof. Dr. M	I. Kläui			
Applicable to the following program			M.Sc. Phys				
Miscellaneous			Sprache: E				
			1	5 .			

Modul 7014	Mo	-	lesungen:	"Quantu	m 08.12	8.7014	
	Spir	ntronics"					
	Module Topical Courses: "Quantum Spintro- nics"						
Compulsory or elective module	WP						
Credit points and workload	6 LP = 180 h						
<b>Duration</b> according to the study plan	1						
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit	
Courses and teaching methods	pe	term	obligation	$\operatorname{time}$	study	points	
Vorlesung mit Übung "Quantum Spin- tronics" (WP)		1	Р		138 h	6 LP	
Vorlesung (WP)	V			3 SWS			
Übung (WP)	Ü			1 SWS			
To complete the module, the follow	ving a	chievements mus	t be made:	· · · · · · · · · · · · · · · · · · ·			
Presence							
Active participation	gemä	iβ §5 Abs. 3					
Course achievements	Erfol	greiche Bearbeitun	g von Übung	saufgaben u	nd/oder P	rojekten	
Module examination	Klau	sur (Umfang 120	Min., Bearl	oeitungszeit	maximal	180 Min.).	
	müno	dliche Prüfung (30	Min), Hausar	rbeit oder eig	gener Vort	rag	
Qualification and program goals / $\cdot$	Comp	etences					
Den Studierenden sollen die physikalise schreibungen bis zum quantenmechanise erzielt werden, wie einzelne Elektronen Magnetisierung führen. Die Dynamik vo thoden zur Messung werden erklärt. Auf cher, Sensorik und Logik eingeführt und emergenten Phänomenen und den Überg Spin verstehen und das Anwendungspote soll ein vertieftes Verständnis für ein fors gute Grundlage darstellt, eine Masterard	hen Ei im Fea n Spin der A Spin-b gang vo ential a schungs	nzelspin nahe gebr stkörper durch die s wird klassisch als nwendungsseite win asierte Qubits werd on klassischen und bschätzen können. snahes Spezialgebie	acht werden. Austauschko auch quante d energiespa en erklärt. S quantenmech An einem od t der kondens	Insbesonder opplung zu e enmechanisch rende Magne tudenten wer nanischen Eff er an mehren sierten Mater	re soll ein V einer makro n besproche etoelektron rden die Ko fekten im I ren speziell	Verständnis oskopischer en und Me ik für Spei- onzepte vor Beispiel des en Themer	
Course content							
Einzel-Spins und resultierende magnetise von Spins, Spindynamik, Mikromagnetis te, Realisierung von QuBits mit Spins, N	mus, S	pin Torque Effekte,	Spin Transp	ort und Mag			
Literature							
Speziellere Lehrbücher der kondensierter densed Matter, J. M. D. Coey: Magne – from fundamentals to nanoscale dyna Veröffentlichungen	tism a	nd Magnetic Mate	rials, J. Stöł	nr & H. c. S	Siegmann:	Magnetism	
Entry requirements							
Recommended prerequisites							
Language				sprache Eng rache Deutse		alisch	

Language	Prüfungssprache Deutsch oder Englisch
Weighting of the achievement in the overall grade	6/120
Module frequency	In der Regel jährlich
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. M. Kläui
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Sprache: Englisch

	Module Topical Courses: "Superconduc- tivity" 08.128.7013					28.7013
Compulsory or elective module	WP				I	
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	time	study	points
Lecture with excercises "Superconduc- tivity" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \ \mathrm{SWS}$		
Excercises (WP)	Ü			$1 \; \mathrm{SWS}$		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	essful completion of	f exercises or	projects		
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.),	term paper
Qualification and program goals /	Comp	etences				
transport properties of the superconduc						nding of the ssibilities of
transport properties of the superconduct dissipation free transport and the realize or qubits. In one or several special topic physics shall be achieved forming the for	ting gr ation c s a dee	round state shall l of superconducting eper understanding	be achieved w quantum ph g of a subfield	vith respect enomena as l of current a	to the po ultrasensi research in	ssibilities of tive sensors a solid state
dissipation free transport and the realiz or qubits. In one or several special topic physics shall be achieved forming the for <b>Course content</b>	eting gr ation o s a dec indatio	round state shall h of superconducting eper understanding on to successfully p	be achieved w quantum ph g of a subfield prepare a mas	with respect enomena as l of current ter thesis on	to the po ultrasensi research in these top	ssibilities of tive sensors a solid state pics.
dissipation free transport and the realiz or qubits. In one or several special topic physics shall be achieved forming the for	eting gr ation c es a dec indatic ber pair au des nsors a ibits, h	round state shall h of superconducting eper understanding on to successfully p formation and con cription, type I and nd as voltage norm nigh temperature s	be achieved w quantum ph g of a subfield prepare a mass indensation in d type II sup- nal, critical cu	with respect enomena as l of current a ter thesis on the ground s erconductors urrents in su	to the po ultrasensi research in these top state, phas s, the Jose perconduc	ssibilities of tive sensors a solid state bics. se transition phson effect ctors, super-
dissipation free transport and the realiz or qubits. In one or several special topic physics shall be achieved forming the for <b>Course content</b> Electrons in solids, BCS-theory for Coop and transport properties Ginzburg-Land and its applications in ultra sensitive ser conducting magnets, superconducting qu systems, related quantum effects as Qua <b>Literature</b>	eting gi ation c s a dee indation eer pair au des nsors a ibits, h ntum I	round state shall h of superconducting eper understanding on to successfully p formation and con- cription, type I and nd as voltage norm high temperature s Hall effect.	be achieved w quantum ph g of a subfield prepare a mass indensation in d type II sup- nal, critical cu uperconducti	vith respect enomena as l of current n ter thesis on the ground s erconductors irrents in su vity, transpo	to the po ultrasensi research in these top state, phas s, the Jose perconduc ort in two-	ssibilities of itive sensors a solid state bics. se transition phson effect ctors, super- dimensional
dissipation free transport and the realize or qubits. In one or several special topic physics shall be achieved forming the for <b>Course content</b> Electrons in solids, BCS-theory for Coop and transport properties Ginzburg-Land and its applications in ultra sensitive ser conducting magnets, superconducting qu systems, related quantum effects as Qua	ting gr ation c s a dee indatic eer pair au des nsors a ibits, h ntum I atter p	round state shall h of superconducting eper understanding on to successfully p formation and con- cription, type I and nd as voltage norm high temperature s Hall effect.	be achieved w quantum ph g of a subfield prepare a mass indensation in d type II sup- nal, critical cu uperconduction of superconduction	vith respect enomena as l of current n ter thesis on the ground s erconductors urrents in su vity, transpo	to the po ultrasensi research in a these top state, phas s, the Jose perconduc ort in two-	ssibilities of itive sensors a solid state bics. se transition phson effect ctors, super- dimensional coduction to
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Modul 752	Module Topical Courses: "Nonequilibri- um phenomena in quantum matter"       08.128.752         WP					8.752
Compulsory or elective module	WP				•	
Credit points and workload	6 LP	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	$\mathbf{term}$	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Nonequilibri- um phenomena in quantum matter" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ad	chievements mus	st be made:	-	•	
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.), 1	term paper
Qualification and program goals /	Comp	etences				

This lecture addresses non-equilibrium phenomena in advanced solids, with focus on systems exhibiting low temperature macroscopic quantum states like superconductivity, charge/spin density waves, ferro- and anti-ferromagnetism. These states can be studied and manipulated by femtosecond optical pulses using the so-called "pump-probe" approach. Femtosecond technology and spectroscopy have experienced major developments in the recent two decades, providing means to femtosecond switching of magnetization, observations of Higgs modes in superconductors and light-induced enhancement of superconductivity, or making molecular movies, just to mention a few.

After introducing the general principle of the "pump-probe" spectroscopy, we will address several case studies, where different experimental techniques (THz spectroscopy, ultrafast electron diffraction, time-resolved ARPES, etc.) will be applied to study one of the above-mentioned macroscopic quantum states. This way we will learn the basics of non-linear optics, the novel laser-based techniques (used both in the lab and at large-scale facilities) and address physics of different material classes with fascinating functional properties.

The course should provide a broad overview of techniques and nonequilibrium phenomena in correlated solids, and thus present solid grounds for M.Sc. work in several areas of research in solid state physics.

#### Course content

Basics of nonlinear optics & ultrafast lasers; Principles of femtosecond real-time spectroscopy and modulation techniques; Femtosecond thermo-modulation in metals; Terahertz generation and THz time-domain spectroscopy; Basics of superconductivity; Electrodynamics of systems with broken symmetry ground states; Dynamics of the superconducting gap; Microwave enhancement of superconductivity; Collective (Higgs) modes in superconductors; Basics of Charge and Spin density waves; Time-resolved photoelectron spectroscopy; Femtosecond X-ray and electron diffraction – making molecular movies; Magnetization dynamics and switching

#### Literature

B.E.A. Saleh, M.C. Teich: Fundamentals of Photonics, Wiley, 1991; Kittel: Introduction to Solid State physics; M. Dressel and G. Grüner: Electrodynamics of Solids; S. Blundell: "Magnetism in Condensed Matter"; Oxford Master Series in Physics; M. Tinkham: Introduction to Superconductivity; G. Grüner: Density waves in solids; selected scientific publications & reviews

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Normally every third semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. J. Demsar

Modul 752	Module Topical Co um phenomena in	ourses: "Nonequilibri- quantum matter"	08.128.752
Applicable to the following program	ns	M.Sc. Physics	
Miscellaneous		Course language: English	

Modul 723	Module Topical Courses: "Introduction to Condensed Matter Theory"       08.128.723         WP       WP					
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and tooshing methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Introduction to Condensed Matter Theory" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	30 Min.), t	term paper
Qualification and program goals /	Comp	etences				

Building on the introductory courses on quantum mechanics and statistical thermodynamics, the central concepts of the description of crystalline solids shall be discussed. Starting from lattice periodicity and crystal symmetry, concepts like the electronic structure (electrons in a crystal field potential) and elementary excitations (phonons, magnons, plasmons, etc.) and their consequences for the various physical properties of solids at low temperatures are explained, thereby creating a solid basis to deal with research-related topics in the field of condensed matter theory.

#### **Course content**

Crystal structure, symmetry, the concept "reciprocal lattice", lattice dynamics in the harmonic approximation, relation to the elastic constants, electrons in a crystal field (Bloch wave and Wannier functions, energy bands, etc.), basic concepts of magnetism, magnons, etc. Also, depending on the choice of the lecturer, selected advanced topics (e.g., scattering theory of solids, electron-phonon interaction, plasmons and dielectric response, etc.) are presented.

Entry requirements	
Recommended prerequisites	
Language	Course language English
	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Every summer semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. P. van Dongen
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 724	Module Topical Courses: "Selected       08.128.724         Chapters of Condensed Matter Theory"       0.00000000000000000000000000000000000					
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	$\operatorname{time}$	study	$\mathbf{points}$
Lecture with excercises "Selected Chap- ters of Condensed Matter Theory" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ing a	chievements mus	t be made:		•	-
Presence						
Active participation	accor	ding to §5 subsecti	ion 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral ex	xamination (	30 Min.), t	erm paper

Qualification and program goals / Competences

Building on the foundations of statistical thermodynamics and/or quantum mechanics of many-body systems, the students will be introduced to specific aspects of the theory of quantum many-particle systems ("hard"condensed matter). Topics to be treated may include the theory of correlated fermions, modern static and dynamic phenomena of magnetism, low-dimensional systems, disorder, quantum phase transitions, many-body theory and their numerical methods, the theory of superfluidity and superconductivity, and topological quantum matter. Having completed this course, the student should have achieved a deeper understanding and a research-level specialization of condensed matter theory, which should form a solid foundation to successfully complete a master's thesis in a related field of physics.

#### Course content

Depending on the lecturer, the lecture may be focused on numerical methods in many-body physics, the theory of correlated fermions, the theory of superconductivity, modern magnetism, or topological systems.

#### Literature

- J. P. Hansen, I. R. McDonald, Theory of Simple Liquids, Academic Press, London 2006;
- J. Yeomans, Statistical Mechanics of Phase Transitions, Clarendon Press, Oxford, 1992;
- A. Onuki, Phase Transition Dynamics, Cambridge University Press, Cambridge, 2002;
- K. Binder, W. Kob, Glassy Materials and Disordered Solids. An Introduction to Their Statistical Mechanics, World Scientific, Singapore, 2005;
- W. Paul, J. Baschnagel, Stochastic Processes, From Physics to Finance, Springer, Berlin, 2000;
- A. Auerbach, Interacting Electrons and Quantum Magnetism, Springer (1994);
- P. Fulde, Electron Correlations in Molecules and Solids, Springer (1995);
- L. Kantorovich, Quantum Theory of the Solid State: An Introduction, Kluwer (2004);
- D.C. Mattis, The Theory of Magnetism Made Simple: An Introduction to Physical Concepts and to Some Useful Mathematical Methods, World Scientific, 2006;

Entry requirements	
Recommended prerequisites	
Language	Course language English
	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Every summer semester
Reasons for compulsory attendance	

Modul 724	Module	Topical	Courses:	"Selected	08.128.724	
	Chapters	of Conde	ensed Matte	er Theory"		
Persons responsible for this module	е		Prof. Dr. P. van Dongen			
Applicable to the following program	licable to the following programs			M.Sc. Physics		
Miscellaneous			Course lang	uage: English		

Modul 725		lule Topical Co ter I"	ourses: "Th	eory of So	ft 08.12	28.725
Compulsory or elective module	WP				I	
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Theory of Soft Matter I" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3  SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ing a	chievements mus	st be made:			
Presence						
Active participation		ding to §5 subsect				
Course achievements		ssful completion of		1 0		
Module examination	Module examination Written exam (120-180 Min.), oral examination (30 Min.), term paper or presentation					
		osemuation				
<b>Qualification and program goals</b> / <b>O</b> The students become acquainted with the		etences	systems with	large fluctua	ations for	the exampl
The students become acquainted with the of various soft matter systems. A special classes.	e statis	e <b>tences</b> tical description of				
The students become acquainted with the of various soft matter systems. A special classes.	e statis focus l	etences tical description of ies on general princ	ciples that ma	y be applied	for differe	ent materia
The students become acquainted with the of various soft matter systems. A special classes.	e statis focus l nd con ies, Br woidin er field als;	etences tical description of ies on general princ servation laws, sca ownian dynamics, g walk, blob conce theory), Membrai	ttering laws, s Critical dyna pt, Flory scre nes (fluid, her	ay be applied self similarity mics; ening, Flory catic and cry	for different and scale Huggins t ystalline n	ent materia e invariance heory, Pat nembranes
The students become acquainted with the of various soft matter systems. A special classes. <b>Course content</b> General concepts: Modeling, symmetry, a mean-field approaches and Landau theor Structure: Polymers (random walk, self-a integral description of polymers, polyme Landau-de Gennes theory of liquid crysta Dynamics: Polymers (Rouse model), hyd quilibrium matter. <b>Literature</b>	e statis focus l nd con ies, Br woidin er field als; lrodyn	etences tical description of ies on general prine servation laws, sca ownian dynamics, g walk, blob conce theory), Membran amics at low Reyr	ttering laws, s Critical dyna pt, Flory scre nes (fluid, her	ay be applied self similarity mics; ening, Flory catic and cry	for different and scale Huggins t ystalline n	ent materia e invariance heory, Pat nembranes
The students become acquainted with the of various soft matter systems. A special classes. Course content General concepts: Modeling, symmetry, a mean-field approaches and Landau theor Structure: Polymers (random walk, self-a integral description of polymers, polyme Landau-de Gennes theory of liquid cryst Dynamics: Polymers (Rouse model), hyd	e statis focus l nd con ies, Br woidin er field als; lrodyn	etences tical description of ies on general prine servation laws, sca ownian dynamics, g walk, blob conce theory), Membran amics at low Reyr	ttering laws, s Critical dyna pt, Flory scre nes (fluid, her	ay be applied self similarity mics; ening, Flory catic and cry	for different and scale Huggins t ystalline n	ent materia e invariance heory, Pat nembranes
The students become acquainted with the of various soft matter systems. A special classes.  Course content General concepts: Modeling, symmetry, a mean-field approaches and Landau theor Structure: Polymers (random walk, self-a integral description of polymers, polyme Landau-de Gennes theory of liquid crysta Dynamics: Polymers (Rouse model), hyd quilibrium matter.  Literature	e statis focus l nd con ies, Br woidin er field als; lrodyn	etences tical description of ies on general prin- servation laws, sca ownian dynamics, g walk, blob conce theory), Membrai amics at low Reyr	ttering laws, s Critical dyna pt, Flory scre nes (fluid, her	ay be applied self similarity mics; ening, Flory catic and cry	for different and scale Huggins t ystalline n	ent materia e invariance heory, Pat nembranes
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The students become acquainted with the of various soft matter systems. A special classes. Course content General concepts: Modeling, symmetry, a mean-field approaches and Landau theor Structure: Polymers (random walk, self-a integral description of polymers, polyme Landau-de Gennes theory of liquid crysta Dynamics: Polymers (Rouse model), hyd quilibrium matter. Literature • de Gennes, Scaling Concepts in Polymer • Doi/Edwards, The Theory of Polymer	e statis focus l nd con ies, Br woidin er field als; lrodyn ner Ph r Dyna anics c	etences tical description of ies on general prine servation laws, sca ownian dynamics, g walk, blob conce theory), Membran amics at low Reyr ysics umics f Macromolecules	ttering laws, s Critical dyna pt, Flory scre nes (fluid, her	ay be applied self similarity mics; ening, Flory catic and cry	for different and scale Huggins t ystalline n	ent materia e invariance heory, Pat nembranes
The students become acquainted with the of various soft matter systems. A special classes. <b>Course content</b> General concepts: Modeling, symmetry, a mean-field approaches and Landau theor Structure: Polymers (random walk, self-a integral description of polymers, polyme Landau-de Gennes theory of liquid cryst: Dynamics: Polymers (Rouse model), hyd quilibrium matter. <b>Literature</b> • de Gennes, Scaling Concepts in Polymer • Doi/Edwards, The Theory of Polymer • Grosberg/Khokhlov, Statistical Mecha	e statis focus l nd com ies, Br woidin er field als; lrodyn ner Ph r Dyna anics c lensed	etences tical description of ies on general prine servation laws, sca ownian dynamics, g walk, blob conce theory), Membrai amics at low Reyn ysics unics of Macromolecules Matter Physics	ttering laws, s Critical dyna pt, Flory scre nes (fluid, her	ay be applied self similarity mics; ening, Flory catic and cry	for different and scale Huggins t ystalline n	ent materia e invarianc heory, Pat nembranes

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Upon request
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. K. Kremer, Prof. Dr. F. Schmid
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

	Module Topical Courses: "Modern       08.128."         Computational Techniques in Condensed/Soft Matter Physics"       08.128."         WP       WP					28.745
Compulsory or elective module	WP					
Credit points and workload	6 LP	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	${f Self} {f study}$	Credit points
Lecture with excercises "Modern Computational Techniques in Conden- sed/Soft Matter Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ing ac	chievements mus	t be made:			-1
Presence						
Active participation	accor	ding to §5 subsecti	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination		en exam (120-180 esentation	Min.), oral ex	xamination (	30 Min.),	term paper
Qualification and program goals /	Comp	etences				
Students attending the course will lear computer simulations in the field of cond These techniques will enable them to st solids, polymer melts etc.), conformation Course content	densed tudy pl al chan	and soft matter pl nenomena like pha ges, chemical react	nysics, possib se transitions	ly including 5 in a variety	molecular y of syste	biophysics. ms (liquids,
The topics of the course will be selected a	ccordir	1 1 .				
sampling techniques, simulation of rare density functional theory, force-field opti-		, critical phenomer	na, non-equil	ibrium dynai	mics, coar	se-graining,
		, critical phenomer	na, non-equil	ibrium dynai	mics, coar	se-graining,
density functional theory, force-field opti-		, critical phenomer	na, non-equil	ibrium dynai	mics, coar	se-graining,
density functional theory, force-field opti- Literature		, critical phenomer	na, non-equil	ibrium dynai	mics, coar	se-graining,
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Modul 801		lule Topical Co ations in Statis	i- 08.12	28.801		
Compulsory or elective module	WP				I	
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Computer Si- mulations in Statistical Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:		1	
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination	Writt	ten exam (120-180 esentation			(30 Min.),	term paper
Qualification and program goals / Competences						
Students will learn to describe complex gorithms, and to implement the algorith They will learn to appreciate the import riment.	ms cor	rectly and in an e	fficient way of	n modern co	mputer a	rchitectures.
Students will learn to describe complex gorithms, and to implement the algorith They will learn to appreciate the import riment. Course content	ams cor	rectly and in an e f computer simula	fficient way of tions in their	n modern co interaction v	mputer an with theor	rchitectures. y and expe-
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Students will learn to describe complex gorithms, and to implement the algorith They will learn to appreciate the import riment. Course content Molecular dynamics simulations, symplet analysis of time series, finite size effects	ctic intrand	rectly and in an e f computer simular egrators, Markov c nulations in differe	fficient way of tions in their hain Monte C ent thermodyn	n modern co interaction v Carlos, rando namic ensem	mputer an with theor m number bles.	rchitectures. y and expe-
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Modul 7010		lule Topical Co nterfaces"	ls 08.12	8.7010		
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and too shing methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	$\mathbf{term}$	obligation	$\operatorname{time}$	$\mathbf{study}$	points
Lecture with excercises "Soft Materials at Interfaces" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ing a	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsecti	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination	or pr	en exam (120-180 esentation	Min.), oral ex	xamination (	30 Min.), t	term paper

#### Qualification and program goals / Competences

The course gives an introduction to the physical principles to understand the structure and dynamics of soft condensed matter adjacent to solid, liquid, and vapor interfaces. Soft matter interfaces are ubiquitous in life and technology, see for example, OLED displays on smartphones, soap bubbles, many biological tissues.

Particular emphasis is given to the links connecting intermolecular forces with molecular scale structure and physical materials properties. The course further introduces the experimental techniques required to study soft matter interfaces on the relevant time and length scales. Focus is set to scattering and scanning probe techniques, providing complementary information in real and reciprocal space.

The course will enable the students to understand numerous physical phenomena surrounding us in everyday live while also providing them with the basic knowledge for improving the performance of modern soft materials for specific applications. Examples help to develop a deeper understanding and to explore links to other branches of physics.

#### Course content

Topics may vary depending on the preferences of the lecturers. Typical topics are

- Thermodynamics of interfaces
- Surface tension
- Self-organization of soft matter thin films
- Charged solid/liquid interfaces and Helmholtz double layer
- Interfacial forces and colloidal stability
- Interface induced phase transitions
- Adsorption and wetting
- Surfactants and Emulsions
- Interfacial freezing and premelting
- Liquids in nanoporous materials
- X-ray scattering and spectroscopy
- Scanning probe techniques and force measurements

#### Literature

- Metin Tolan, "X-Ray Scattering from Soft-Matter Thin Films", Springer (1999).
- Jens Als-Nielsen, Des McMorrow, "Elements of Modern X-ray Physics", 2nd Edition, Wiley (2011).
- Peter S. Pershan , Mark Schlossman, "Liquid Surfaces and Interfaces : Synchrotron X-ray Methods", Cambridge University Press (2012).
- Hans-Jürgen Butt, Karlheinz Graf, Michael Kappl, "Physics and Chemistry of Interfaces", 3rd Edition, Wiley (2013).

Entry requirements	
Recommended prerequisites	

Modul 7010	Module Topical Co at Interfaces"	08.128.7010		
Language		Course language English Examination language English or German		
Weighting of the achievement in the overall grade		6/120		
Module frequency		Annually		
Reasons for compulsory attendance				
Persons responsible for this module		Prof. Dr. Hans-Jürgen Butt, Prof. Dr. Tho- mas Palberg, Prof. Dr. F. Schmid		
Applicable to the following program	ns	M.Sc. Physics		
Miscellaneous		Course language: English		

Modul 753	Mod	Module Topical Courses: "Biophysics"				8.753
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and too shing methods	Ty- Designated Degree of Contact Self Credit					Credit
Courses and teaching methods	pe	term	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Biophysics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:		•	
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		Written exam (120-180 Min.), oral examination (30 Min.), term paper or presentation				
Qualification and program goals /	Comp	etences				
The course gives an introduction to phenomena in biological matter using concepts from theoretical physics in						

The course gives an introduction to phenomena in biological matter using concepts from theoretical physics in order to expose and understand common physical principles. Students will learn about the elementary molecular components of a cell, as well as the interactions of these components and the formation of hierarchical functional structures. The course will enable students to understand and approach phenomena in biological systems from a physics perspective. Particular attention is given to the application of established concepts from soft matter physics and their application to living matter.

#### **Course content**

There will be an introduction to living matter (tissue, bacteria, cells, etc.) and its organization, as well as the molecular players (proteins, polymers, enzymes). Further topics may vary depending on the preferences of the lecturers. Typical topics include:

- Stochastic dynamics, diffusion, and single molecule dynamics
- Basics of non-equilibrium thermodynamics and information theory
- Physical limits to sensing
- Biochemical networks and criticality
- Mechanochemical coupling, molecular motors and force generation
- Collective behavior and phase behavior
- Self-organization and structure formation
- X-ray scattering and the structure of proteins
- Membranes and their theoretical description

#### Literature

• William Bialek, Biophysics: Searching for Principles, Princeton University Press (2013).

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	irregular
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. Thomas Speck, Prof. Dr. Friederike Schmid
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 754	Module Topical Courses: "Advanced theoretical solid state physics"       08.128.754         Module Topical Courses: "Advanced theoretical solid state physics"       08.128.754					
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	an 1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Advanced theoretical solid state physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ad	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsecti	ion 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.), t	term paper
Qualification and program goals /	Comp	etences				
Qualification and program goals / Competences Students shall get acquainted with basic and advanced concepts and methods of theoretical solid state physics. They will learn fundamentals concepts of electronic structure theory that explain the stability of matter, of sym- metries that govern many structural properties of matter, of transport mechanisms, and of the role of excitations and defects for many material properties in solid matter. The class will provide basic knowledge to prepare them for more advanced classes in solid state theory and for conducting a master thesis in Condensed Matter Theory or Experiment.						

#### **Course content**

Crystal symmetries, Reciprocal lattice, Phonons, Electron gas, Band structure, Methods for calculating Band Structure, Fermi surface, Conductors and Semiconductors, Quasiparticles concepts, Defects and Disordered systems, Transport, Optical properties, Magnetism, Superconductivity

Literature

- Ashcroft, Mermin: Solid State Physics, Saunders College
- Kittel: Quantum Theory of Solids, Wiley
- Jones, March, Theoretical Solid State Physics, Vol 1,2, John Wiley
- Ziman, Principles of the Theory of Solids, Cambridge University Press

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Each summer semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. J. Sinova
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 800	Module Topical Courses: "Theory of Soft08.128.800Matter II"0.128.800				8.800	
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	$\mathbf{term}$	obligation	time	study	points
Lecture with excercises "Theory of Soft		2	Р		138 h	6 LP
Matter II" (WP)			1		130 11	0 11
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ac	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination	Writt	en exam (90-180 N	In.) or oral	examination	(30 Min.)	
Qualification and program goals /	Comp	etences				

The students get acquainted with the statistical description of systems with large fluctuations, given the example of different soft matter systems. Special focus lies on general principles which can be applied for different material classes.

#### Course content

Topics are selected depending on the preferences of the lecturers. Possible topics are: DLVO theory, hydrodynamic interactions in colloids and polymers, micro swimmers and active particles, Zimm model, reptation model, networks and rubber elasticity, structure of polyelectrolytes, viscoelasticity, materials science aspects of soft matter systems, statistical physics of interfaces, wetting, capillary waves.

#### Literature

- de Gennes, Scaling Concepts in Polymer Physics
- Doi/Edwards, The Theory of Polymer Dynamics
- Grosberg/Khokhlov, Statistical Mechanics of Macromolecules
- Chaikin/Lubensky, Principles of Condensed Matter Physics
- Russel/Saville/Schowalter, Colloidal Dispersions.
- Dhont: An Introduction to Dynamics of Colloids

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. K. Kremer, Prof. Dr. F. Schmid
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

## 3.3.2 Quantum, Atomic and Neutron Physics

Modul 729	Module Topical Courses: "Quantum Op- tics (Q-Ex-1)" 08.128.729					
	tics	(Q-Ex-1)"				
Compulsory or elective module	WP					
Credit points and workload		P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Quantum Op- tics" (WP), frequently joint theoretical- experimental course		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ac	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral ex	xamination (	(30 Min.),	term paper
Qualification and program goals /	Comp	etences				
fields. Course content						
Basic entry course to experimental quantu jointly by experimentalists and theorists Contents:	-	ıcs. Interdisciplinaı	y experiment	-theory cour	se, frequer	ntly lectured
• Quantization of electromagnetic fields			ation fields			
<ul><li>Quantization of electromagnetic fields</li><li>correlations in the radiation field and</li></ul>	in pho	oton statistics				
<ul> <li>Quantization of electromagnetic fields</li> <li>correlations in the radiation field and</li> <li>quantized interaction of atoms with life</li> <li>"dressed states"</li> <li>Further possible topics:</li> <li>Photon detectors</li> </ul>	in pho ight, Ja	oton statistics aynes-Cummings H				
<ul> <li>Quantization of electromagnetic fields</li> <li>correlations in the radiation field and</li> <li>quantized interaction of atoms with life</li> <li>"dressed states"</li> <li>Further possible topics:</li> </ul>	in pho ight, Ja	oton statistics aynes-Cummings H				
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Modul 729	Module Topical Co tics (Q-Ex-1)"	08.128.729	
Module frequency	Module frequency		
Reasons for compulsory attendance			
Persons responsible for this module	Prof. Dr. J. Walz		
Applicable to the following programs		M.Sc. Physics	
Miscellaneous		Course language: English	

Modul 803	Module Topical Courses: "Photonics (Q- Ex-2)"					
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
	ре	term	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Photonics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the following achievements must be made:						
Presence						
Active participation	according to §5 subsection 3					
Course achievements	successful completion of exercises or projects					
Module examination	Written exam (120-180 Min.), oral examination (30 Min.), term paper or presentation					
Qualification and program goals / Competences						

The students shall be introduced to the advanced description of light propagation and the interaction with matter. A deep understanding of laser spectroscopy – based on incoherent and coherent licht-matter interaction and highly stable lasers shall be acquired; in particular the difference between coherent and incoherent processes will be detailed. The students should learn to understand the working principle of lasers and fundamentals of non-linear optics.

#### **Course content**

Fundamentals of experimental quantum physics. Possible topics:

- Gaussian optics and resonators
- connection between classical, semi-calssical and quantum mechanical description of light-matter interaction
- coherent light and lasers
- laser modulators, optical fibers
- short pulses and frequency comb techniques
- incoherent spectroscopy techniques (absorption, fluorescence, Doppler-free, frequency modulation)
- comparison with coherent techniques (Rabi, Ramsey, Spin-Echo)
- non-linear media, sum- and difference frequency generation,  $\chi^{(2)}$  vs.  $\chi^{(3)}$  processes,
- laser cooling

#### Literature

Specialized textbooks in photonics , e.g.

- Laser Spectroscopy, W. Demtröder
- Optics, Light and Lasers, D. Meschede
- Lasers, A.E. Siegman
- Fundamentals of Photonics, B. E. A. Saleh und M.C. Teich
- publications close to current research.

Entry requirements			
Recommended prerequisites			
Language	Course language English		
Language	Examination language English or German		
Weighting of the achievement in the overall grade	6/120		
Module frequency	Annually in summer term		
Reasons for compulsory attendance			

Modul 803	Module Topical Courses: "Photonics (Q- Ex-2)"		
Persons responsible for this module	е	Prof. Dr. K. Wendt, Prof.	Dr. J, Walz
Applicable to the following program	ns	M.Sc. Physics	
Miscellaneous		Course language: English	

Modul 804	Module Topical Courses: "Quantum In- formation (O Fr 2)"					28.804
	formation (Q-Ex-3)"					
Compulsory or elective module	WP					
Credit points and workload	6 LP	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of obligation	Contact	Self	Credit
	pe	term	obligation	time	study	points
Lecture with excercises "Quantum In- formation " (WP), frequently joint		1	Р		138 h	6 LP
theoretical-experimental course		L	Г		130 11	0 LF
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ac	chievements mus	t be made:		1	
Presence , and the second seco						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements		ssful completion of		projects		
Module examination		en exam (120-180		1 0	(30 Min.).	term paper
		esentation	))		( ))	I II
Qualification and program goals /	Compe	etences				
<ul> <li>the experimental side, concepts, experimental realizations, platforms and applications of these concepts will be introduced involving the necessary aspects of quantum optics.</li> <li><b>Course content</b></li> <li>Advanced course in the field of quantum optics, atomic physics and its application to quantum information "Stand-alone" course, applies concepts from Quantum Optics and many boy physics. Interdisciplinary course frequently lectured jointly by experimentalists and theorists.</li> <li>Contents: <ul> <li>storage and processing to quantum information in different systems</li> <li>lead to quantum communication and computing</li> <li>entangled states, quantum jumps, quantum Zeno effect</li> <li>decoherence, macroscopical quantum superposition ("Schrödinger cat states")</li> </ul> </li> <li>Further possible topics:</li> </ul>						
<ul> <li>introduced involving the necessary aspect</li> <li>Course content</li> <li>Advanced course in the field of quantur</li> <li>"Stand-alone" course, applies concepts of frequently lectured jointly by experiment Contents:</li> <li>storage and processing to quantum in</li> <li>lead to quantum communication and</li> <li>entangled states, quantum jumps, quantum</li> </ul>	m opti from Q talists a format compu	uantum optics. cs, atomic physics Quantum Optics ar and theorists. tion in different sys ting Zeno effect	and its app ad many boy stems	lication to c physics. Int	quantum i	nformation.
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Modul 804	Module Topical Courses: "Quantum In- formation (Q-Ex-3)" 08.128.			
Language		Course language English Examination language Eng	lish or German	
Weighting of the achievement in th	e overall grade	6/120		
Module frequency		Annually in summer term		
Reasons for compulsory attendance	9			
Persons responsible for this module	e	Prof. Dr. F. Schmidt-Kaler		
Applicable to the following program	ns	M.Sc. Physics		
Miscellaneous		Course language: English		

Modul 805	Module Topical Courses: "Precision fun- damental physics (Q-Ex-4)"08.128.805					8.805
Compulsory or elective module	WP					
Credit points and workload	6 LP	h = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and tenshing methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	$\operatorname{time}$	$\mathbf{study}$	points
Lecture with excercises "Precision fun-		1	Р		138 h	6 LP
damental physics" (WP)		-	-		100 1	0 21
Lecture (WP)	V			$3 \ \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ad	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral ex	xamination (	30 Min.), t	erm paper

### Qualification and program goals / Competences

Current dedicated measurements have reached fascinating levels of experimental precision and can explore fundamental questions of physics and cosmology. These include: fundamental symmetries of physics, precision measurements in neutron decay, tests of the weak interaction, tests of CPT invariance, precision measurements of fundamental constants, and modern experiments in gravitation. The students shall be introduced to problems of modern atomic physics, quantum physics, neutron physics, and cosmology. The students shall profoundly deal with these topics, close to current research.

### **Course content**

Discrete symmetries and fundamental interactions in physics

- tests of QED and CP violation, CPT-invariance, time reversal symmetry
- weak interaction, matter/ antimatter asymmetry, EDM
- variation of fundamental constants tests of the equivalence principle, Newton's gravitation law at short distances

Methods

• Atoms, neutrons, protons, antimatter, penning traps, mass spectrometry

Neutron Physics

• the neutron as probe – structure analysis of matter, properties of the neutron and measurements, interaction with matter, neutron sources, detectors, quantum effects in neutron optics

- Textbooks in atomics physics
- proceedings of summer-schools
- publications close to current research.

Entry requirements	
Recommended prerequisites	
Language	Course language English
Language	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Annually in winter term
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. J. Walz
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

# 3.3.3 Nuclear and Particle Physics

	Module Topical Courses: "Statistics, Da- ta Analysis and Simulation"08.128.730					28.730
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	time	$\mathbf{study}$	points
Lecture with excercises "Statistics, Da-		2 (1)	WP		138 h	6 LP
ta Analysis and Simulation" (WP)		2 (1)	**1		100 11	0 11
Lecture	V			3 SWS		
Excercises	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	t be made:			
Presence		1				
Active participation		ding to §5 subsection				
Course achievements		essful completion of		1 0		
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (	30 Min.),	term paper
Qualification and program goals /	Comp	etences				
area of physics.						
Course content The following areas shall be covered: • Probability distributions and the statt • error propagations and the estimation • significance levels and decisions on hy • Monte Carlo methods, as well as • Statistical analysis methods.	n of pa	rameters;	.;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul>	n of pa	rameters;	;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> Literature	n of pa	rameters;	;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> Literature <ul> <li>R.J. Barlow, Statistics</li> </ul>	n of pa	rameters;	.;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> </ul>	n of pa vpothes	rameters; ses;	.;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high er</li> </ul>	n of pa vpothes	rameters; ses;	.;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high en</li> </ul>	n of pa vpothes	rameters; ses;	.;			
<ul> <li>The following areas shall be covered:</li> <li>Probability distributions and the statt</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high er</li> </ul>	n of pa vpothes	rameters; ses;				
The following areas shall be covered: <ul> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high en</li> </ul> <b>Entry requirements Recommended prerequisites Language</b>	n of pa vpothes nergy p	rameters; ses; bhysics	Course lang Examinatio	guage Englisi on language I		German
The following areas shall be covered: <ul> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> Literature <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high er</li> </ul> Entry requirements Recommended prerequisites Language Weighting of the achievement in the	n of pa vpothes nergy p	rameters; ses; bhysics	Course lang Examinatio 6/120	on language I	English or	German
The following areas shall be covered: <ul> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high en</li> </ul> <b>Entry requirements Recommended prerequisites Language</b> Weighting of the achievement in the	n of pa /pothes nergy p nergy p	rameters; ses; bhysics	Course lang Examinatio 6/120		English or	German
The following areas shall be covered:  Probability distributions and the state error propagations and the estimation significance levels and decisions on hy Monte Carlo methods, as well as Statistical analysis methods. Literature R.J. Barlow, Statistics Glen Cowan, Statistical data analysis Olaf Behnke, Data analysis in high er Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	n of pa /pothes nergy p nergy p nergy p	rameters; ses; bhysics	Course lang Examinatic 6/120 Every summ	n language I mer semester	English or	German
The following areas shall be covered: <ul> <li>Probability distributions and the state</li> <li>error propagations and the estimation</li> <li>significance levels and decisions on hy</li> <li>Monte Carlo methods, as well as</li> <li>Statistical analysis methods.</li> </ul> <b>Literature</b> <ul> <li>R.J. Barlow, Statistics</li> <li>Glen Cowan, Statistical data analysis</li> <li>Olaf Behnke, Data analysis in high en</li> </ul> <b>Entry requirements Recommended prerequisites Language</b> Weighting of the achievement in the	n of pa /pothes nergy p nergy p nergy p	rameters; ses; bhysics	Course lang Examinatic 6/120 Every sum Prof. Dr. M	n language I mer semester I. Schott	English or	
The following areas shall be covered:  Probability distributions and the state error propagations and the estimation significance levels and decisions on hy Monte Carlo methods, as well as Statistical analysis methods. Literature R.J. Barlow, Statistics Glen Cowan, Statistical data analysis Olaf Behnke, Data analysis in high er Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	n of pa /pothes /pothes /pothes / nergy p le over / / / /	rameters; ses; bhysics	Course lang Examinatic 6/120 Every sum Prof. Dr. M	n language I mer semester	English or	

Modul 731	Module Topical Courses: "Particle De- tectors" 08.128.731					28.731
Compulsory or elective module	WP				I	
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and tenching methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	time	study	points
Lecture with excercises "Particle Detectors" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ad	chievements mu	st be made:		•	
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion o	f exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination	(30 Min.),	term paper
Qualification and program goals /	Comp	etences				
Course content The following subjects shall be covered: • Particle sources and accelerators;						
• Detection methods for charged and n	eutral	radiation;				
• Data acquisition;						
• Particle detectors to measure time, en	nergy, 1	momentum and pa	article type;			
• Applications in complex detector syst	tems.					
Literature						
• K. Kleinknecht, Detectors for particle	e radiat	tion				
• C. Grupen, B. Shwartz, Particle Dete	ectors					
Entry requirements						
Recommended prerequisites						
Language				guage Englis		
				on language	English or	German
Weighting of the achievement in th	ne over	all grade	6/120			
Module frequency			Every wint	er semester		
Reasons for compulsory attendance				- ~ -		
Persons responsible for this module	е		Prof. Dr. M	1. Schott		
			110			
Applicable to the following program Miscellaneous	ns		M.Sc. Phys	sics guage: Engli	,	

Modul 732	and General Relativity"					28.732
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1				-	
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and reaching methods	pe	term	obligation	time	study	points
Lecture with excercises "Cosmology and General Relativity" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsecti	on $3$			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.),	term paper
the current concepts and phenomena of Course content						
General coordinate transformations, diff Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma	, big-b	ang nucleosynthesi				
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature	r, big-b atter a:	ang nucleosynthesi				
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode	r, big-b atter a:	ang nucleosynthesi				
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode Entry requirements	r, big-b atter a:	ang nucleosynthesi				
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode	r, big-b atter a:	ang nucleosynthesi	s, cosmic mic	rowave back	ground, st	
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode Entry requirements	r, big-b atter a:	ang nucleosynthesi	s, cosmic mic		ground, st	cructure de-
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma <b>Literature</b> e.g. Carroll, Wald, Kolb & Turner, Dode <b>Entry requirements</b> <b>Recommended prerequisites</b> <b>Language</b> Weighting of the achievement in the	r, big-b atter a elson	ang nucleosynthesi nd dark energy.	s, cosmic mic	rowave back	ground, st	cructure de-
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	r, big-b atter a elson le over	ang nucleosynthesi nd dark energy.	s, cosmic mic Course lang Examinatic	rowave back	ground, st	cructure de-
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	r, big-b atter a elson ne over	ang nucleosynthesi nd dark energy.	s, cosmic mic Course lang Examinatic 6/120	rowave back guage Englis n language l	ground, st	cructure de-
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance Persons responsible for this module	r, big-b atter a: elson e over e e	ang nucleosynthesi nd dark energy.	s, cosmic mic Course lang Examinatic 6/120 Prof. Dr. M	rowave back guage Englis n language l I. Neubert	ground, st	cructure de-
Friedmann-Robertson-Walker cosmology velopment in the early universe, dark ma Literature e.g. Carroll, Wald, Kolb & Turner, Dode Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	r, big-b atter a: elson e over e e	ang nucleosynthesi nd dark energy.	s, cosmic mic Course lang Examinatic 6/120 Prof. Dr. M M.Sc. Phys	rowave back guage Englis n language l I. Neubert	h English or	cructure de-

Modul 733	Module Topical Courses: "Symmetries in Physics"					8.733		
Compulsory or elective module	WP							
Credit points and workload	6 LP = 180 h							
<b>Duration</b> according to the study plan	1							
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	$\begin{array}{c} {\bf Contact} \\ {\bf time} \end{array}$	${f Self} {f study}$	Credit points		
Lecture with excercises "Symmetries in Physics" (WP)		1	Р		138 h	6 LP		
Lecture (WP)	V			3 SWS				
Excercises (WP)	Ü			1 SWS				
To complete the module, the follow	ving a	chievements mus	t be made:					
Presence								
Active participation	accor	ding to §5 subsecti	on 3					
Course achievements	succe	ssful completion of	exercises or	projects				
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	30 Min.),	term paper		
The lectures' program goal is to provide <b>Course content</b> Group theory, representations, unitary sy								
physics.	ymmet	nes, me groups, ap	plications an	d exercises in		and nuclear		
Literature								
e.g. Georgi, Tung								
Entry requirements								
Recommended prerequisites								
Language	Language			Course language English Examination language English or German				
Weighting of the achievement in th	e over	all grade	6/120					
Module frequency								
Reasons for compulsory attendance	e							
Persons responsible for this module			Prof. Dr. M					
Applicable to the following program	ns		M.Sc. Phys					
Miscellaneous			Course lang	guage: Englis	sh			

Modul 734	Module Topical Courses: "Modern Me- thods in Theoretical High Energy, Par- ticle and Nuclear Physics"					28.734
Compulsory or elective module	WP					
Credit points and workload	6 LF	6 LP = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Modern Me- thods in Theoretical High Energy, Par- ticle and Nuclear Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	essful completion of	f exercises or	projects		
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.),	term paper
Qualification and program goals / The lectures' program goal is to provide of high energy, particle and nuclear phy	e a basi	c understanding of	-			
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content	e a basi vsics. A	c understanding of n additional goal	is to teach th	e methods v	which are	required for
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change en- than once and the module will not be con-	e a basi vsics. A it on a uge the n mecha y, strin very se	current scientifical cory, effective field anics und quantum g theory) and other mester. In this cas	topic from the theories, mate field theory, ers. Lectures	e methods we be following r hematical as concepts of r of this mod	which are research ar spects of p nodel build ule are off	required for eas: electro- perturbation ding beyond ered by dif-
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice ga theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change e than once and the module will not be co Literature	e a basi vsics. A ut on a uge the n mecha y, strin very se punted	c understanding of an additional goal current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	topic from the theories, mate field theory, ers. Lectures	e methods we be following r hematical as concepts of r of this mod	which are research ar spects of p nodel build ule are off	required for eas: electro- perturbation ding beyond ered by dif-
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change e than once and the module will not be co Literature various textbooks, publications close to	e a basi vsics. A ut on a uge the n mecha y, strin very se punted	c understanding of an additional goal current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	topic from the theories, mate field theory, ers. Lectures	e methods we be following r hematical as concepts of r of this mod	which are research ar spects of p nodel build ule are off	required for eas: electro- perturbation ding beyond ered by dif-
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change en- than once and the module will not be con- Literature various textbooks, publications close to Entry requirements	e a basi vsics. A ut on a uge the n mecha y, strin very se punted	c understanding of an additional goal current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	topic from the theories, mate field theory, ers. Lectures	e methods we be following r hematical as concepts of r of this mod	which are research ar spects of p nodel build ule are off	required for eas: electro- perturbation ding beyond ered by dif-
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change e than once and the module will not be co Literature various textbooks, publications close to	e a basi vsics. A ut on a uge the n mecha y, strin very se punted	c understanding of an additional goal current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	topic from the theories, mathematic field theory, ers. Lectures a student of a student of the theory	e methods we be following r hematical as concepts of r of this mod	which are research ar spects of p nodel build ule are off e to this m	required for eas: electro- perturbation ding beyond fered by dif- nodule more
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change e than once and the module will not be con Literature various textbooks, publications close to Entry requirements Recommended prerequisites	e a basi vsics. A ut on a uge the a mecha y, strin very se punted science	c understanding of an additional goal is current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	topic from the theories, mathematic field theory, ers. Lectures a student of a student of the theory	e methods w e following r hematical as concepts of r of this mod an subscribe guage Englis	which are research ar spects of p nodel build ule are off e to this m	required for eas: electro- perturbation ding beyond fered by dif- nodule more
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change e than once and the module will not be con- Literature various textbooks, publications close to Entry requirements Recommended prerequisites Language	e a basi vsics. A ut on a uge the a mecha y, strin very se punted science	c understanding of an additional goal is current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	is to teach the topic from the theories, mathematical field theory, ers. Lectures a student of Course lang Examination	e methods w e following r hematical as concepts of r of this mod an subscribe guage Englis	which are research ar spects of p nodel build ule are off e to this m	required for eas: electro- perturbation ding beyond fered by dif- nodule more
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The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pr weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetr ferent lecturers and topics can change en- than once and the module will not be con- Literature various textbooks, publications close to Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	e a basi vsics. A ut on a uge the n mecha y, strin very se punted science ne over	c understanding of an additional goal is current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	is to teach the topic from the theories, mathematical field theory, ers. Lectures a student of Course lang Examination 6/120	e methods w e following r hematical as concepts of r of this mod an subscribe guage Englis	which are a spects of p nodel build ule are off e to this m h English or	required for eas: electro- berturbation ding beyond fered by dif- nodule more
The lectures' program goal is to provide of high energy, particle and nuclear phy the masters's thesis. Course content Concerning to the lecturer the focus is pre- weak and strong interactions, lattice gas theory, functional integration in quantum the standard model (e.g. supersymmetric ferent lecturers and topics can change en- than once and the module will not be con- Literature various textbooks, publications close to Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	e a basi vsics. A ut on a uge the n mecha y, strin very se punted science ne over e e	c understanding of an additional goal is current scientifical eory, effective field anics und quantum og theory) and other mester. In this cas as identical.	is to teach the topic from the theories, mathematical field theory, ers. Lectures a student of Course lang Examination 6/120	e methods w e following r hematical as concepts of r of this mod- an subscribe guage Englis on language f. Neubert, l	which are a spects of p nodel build ule are off e to this m h English or	required for eas: electro- berturbation ding beyond fered by dif- nodule more

Modul 735	Module Topical Courses: "Accelerator 08.128.735 Physics"					8.735
Compulsory or elective module	WP				· ·	
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	time	study	points
Lecture with excercises "Accelerator Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:		•	
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.), t	erm paper
Qualification and program goals /	Comp	etences				

The purpose of the lecture is to provide an understanding of the underlying physical principles of modern particle accelerators and radiation sources. This concerns in particular the layout of pivotal components such as magnetic structures and radiofrequency-systems. Another objective is to teach the mathematical framework with respect to analytical and numerical methods. Such knowledge will form a suitable basis for doing a master's thesis within the accelerator physics groups at Mainz university.

### **Course content**

Linear and non linear beam-dynamics, in conjunction with properties of linear and recirculating accelerators. Building blocks of beam transport systems, e.g. normal und superconducting magnets. Radiofrequency systems for charged particle acceleration, including superconducting systems. Introduction to superconductivity. Introduction to radiation physics (Synchrotron-radiation), Collective effects, e.g. free electron laser. Recent developments such as energy recovery linacs.

### Literature

• H. Wiedemann, Particle Accelerator Physics Bd. 1&2

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Every winter semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. K. Aulenbacher
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 737	Module Topical Courses: "Astroparticle08.128.737Physics"					
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	$\mathbf{term}$	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Astroparticle Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	30 Min.), t	erm paper
Qualification and program goals /	Comp	etences				

The course provides an overview of cosmology and astroparticle physics and of topical research themes. It provides essential knowledge to successfully complete a master's thesis in a related subject area.

#### Course content

The main themes of the course relate to:

- Cosmology and the evolution of the Universe
- Dark matter and
- Cosmic radiation of charged particles, neutrinos, and gammas as well as gravitational waves.

The subject "cosmology and evolution of the universe" covers cosmological models and parameters, cosmological distances and related measurements, the matter/antimatter problem, the synthesis of light elements, the microwave background radiation, structure formation, the formation, classification, development of galaxies, active galactic nuclei and galaxy clusters, as well as the formation, energy budget, development, and final stages of stars, including the related nucleosynthesis. The theme "dark matter"covers the evidence, as well as direct and indirect searches performed to detect viable particle candidates. Keywords important for the chapter on "cosmic rays" are: sources, composition, propagation, and detection of charged cosmic radiation, sources and detection of resolved and diffuse gamma-ray sources, determination of neutrino properties (oscillations, direct mass measurement, neutrino-less double beta decay), sources and detection of terrestrial and astrophysical neutrinos, the theory and prospective sources of gravitational waves, as well as their indirect and direct detection.

- A. Liddle, An introduction to modern cosmology
- P. Schneider, Extragalaktische Astronomie und Kosmologie
- C. Grupen, Astroteilchenphysik
- D. Perkins, Particle Astrophysics

Entry requirements	
Recommended prerequisites	
Language	Course language English
	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Every summer semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. U. Oberlack
Applicable to the following programs	M.Sc. Physics

Modul 737	Module Topical Co Physics"	ourses: "Astroparticle	08.128.737
Miscellaneous	iscellaneous		

Modul 738	Module Topical Courses: "Particle Phy- sics"08.128.738					
Compulsory or elective module	WP	WP				
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Particle Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3  SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.), t	term paper
Qualification and program goals /	Comp	etences				

The course is intended to deepen the understanding of the fundamental building blocks of matter and their interactions. Basic principles will be covered by using topical research as an example. The course provides the required knowledge in order to successfully complete a master's thesis in a related subject.

### **Course content**

The following subjects shall be covered:

- Brief outline of experimental methods,
- Symmetries and the quark model,
- Lepton scattering at high energies,

• Particles and interaction in the Standard Model, as well as models for its unification and extension. While covering the subjects, ground breaking and actual experiments will be discussed. Depending on the docent's interest, extension of the Standard Mode or bound systems will be covered in more detail.

- C. Berger, Elementarteilchenphysik, Springer-Verlag, 2006.
- D. Griffiths, Introduction to Elementary Particles, Wiley-VCH Verlag, 2008.
- E. Lohrmann, Hochenergiephysik, Teubner-Verlag, 2005.
- D. H. Perkins, High Energy Physics
- B. Povh et al., Teilchen und Kerne

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Every semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. M. Schott
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

	Module Topical Courses: "Theoretical       08.128.809         Particle Physics"       08.128.809					28.809
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Theoretical Particle Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (	(30 Min.),	term pape
The lecture course "Theoretical Particl Quantum Field Theory". The lectures' pr of quantum field theory which are requir	rogram	goal is to provide	a basic under	standing of o		
Quantum Field Theory". The lectures' pr	rogram red for tions, r	goal is to provide a MA thesis in the enormalization in G	a basic under coretical part	standing of o	concepts a	nd method
Quantum Field Theory". The lectures' proof quantum field theory which are require <b>Course content</b> Path integral formalism, quantum correct theories, quantum chromodynamics (QC	rogram red for tions, r	goal is to provide a MA thesis in the enormalization in G	a basic under coretical part	standing of o	concepts a	nd method
Quantum Field Theory". The lectures' proof quantum field theory which are require <b>Course content</b> Path integral formalism, quantum correct theories, quantum chromodynamics (QC of particle physics.	tions, r	goal is to provide a MA thesis in the enormalization in G	a basic under coretical part	standing of o	concepts a	nd method
Quantum Field Theory". The lectures' prof quantum field theory which are required <b>Course content</b> Path integral formalism, quantum correct theories, quantum chromodynamics (QC of particle physics. Literature	tions, r	goal is to provide a MA thesis in the enormalization in G	a basic under coretical part	standing of o	concepts a	nd method
Quantum Field Theory". The lectures' proof quantum field theory which are required <b>Course content</b> Path integral formalism, quantum correct theories, quantum chromodynamics (QC of particle physics. Literature Peskin & Schroeder, Ryder, Schwartz, Ze	tions, r	goal is to provide a MA thesis in the enormalization in G	a basic under coretical part	standing of o	concepts a	nd method
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Quantum Field Theory". The lectures' prof quantum field theory which are require Course content Path integral formalism, quantum correct theories, quantum chromodynamics (QC of particle physics. Literature Peskin & Schroeder, Ryder, Schwartz, Ze Entry requirements Recommended prerequisites Language	rogram red for tions, r D), spe	goal is to provide a MA thesis in the enormalization in C ontaneous symmet	a basic under coretical part QED, renorma ry breaking, I Course lang Examinatic 6/120	standing of o icle physics. alization grou Higgs mecha guage Englis	ip; non-Ak nism, stan	nd method pelian gaug dard mode
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Modul 751	Module Topical Courses: "Theoretical Nuclear Physics"08.128.751					28.751
Compulsory or elective module	WP					
Credit points and workload	6 LP	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	${f Self} {f study}$	Credit points
Lecture with excercises "Theoretical Nuclear Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ac	chievements mus	st be made:			
Presence						
Active participation	accore	ding to §5 subsect	ion 3			
Course achievements	succes	ssful completion o	f exercises or	projects		
Module examination		en exam (120-180 esentation	Min.), oral e	xamination (	30 Min.),	term paper
Qualification and program goals / The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked	lents wi and to	ith a survey of nu- pics. While the fo	cus is on the	oretical aspec	ts of nucl	ear physics,
The aim of this course is to provide studintroduction to modern nuclear theories	lents wi and to l to rece es, Theo s for nu	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta	cus is on theorogress and a	oretical aspect applications, decays, Typ	ets of nucl e.g. to ast bes of nuc	ear physics, crophysics. lear spectra
The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked <b>Course content</b> Introduction to nuclei and nuclear force and EM transitions, Few-body methods	lents wi and to l to rece es, Theo s for nu	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta	cus is on theorogress and a	oretical aspect applications, decays, Typ	ets of nucl e.g. to ast bes of nuc	ear physics, crophysics. lear spectra
The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked <b>Course content</b> Introduction to nuclei and nuclear force and EM transitions, Few-body methods astrophysics and formation of the element	lents wi and to l to rece es, Theo s for nu nts.	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta iclei, Many-body	cus is on theorogress and a	oretical aspect applications, decays, Typ	ets of nucl e.g. to ast bes of nuc	ear physics, crophysics. lear spectra
The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked <b>Course content</b> Introduction to nuclei and nuclear force and EM transitions, Few-body methods astrophysics and formation of the element <b>Literature</b> Text books on nuclear physics, e.g.	lents wi and to l to rece es, Theo s for nu nts.	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta nclei, Many-body : hysics.	cus is on theorogress and a	oretical aspect applications, decays, Typ	ets of nucl e.g. to ast bes of nuc	ear physics, crophysics. lear spectra
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The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked <b>Course content</b> Introduction to nuclei and nuclear force and EM transitions, Few-body methods astrophysics and formation of the element <b>Literature</b> Text books on nuclear physics, e.g. • Samuel S.M. Wong, Introductory Nuclear Physics	lents wi and to l to rece es, Theo s for nu nts. clear Pl in a Nu	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta aclei, Many-body : hysics. utshell.	cus is on theorogress and a	oretical aspect applications, decays, Typ	ets of nucl e.g. to ast bes of nuc	ear physics, crophysics. lear spectra
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The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked <b>Course content</b> Introduction to nuclei and nuclear force and EM transitions, Few-body methods astrophysics and formation of the element <b>Literature</b> Text books on nuclear physics, e.g. • Samuel S.M. Wong, Introductory Nucleise Carlos A. Bertulani, Nuclear Physics • Kenneth S. Krane, Introductory Nucleise <b>Entry requirements</b>	lents wi and to l to rece es, Theo s for nu nts. clear Pl in a Nu	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta aclei, Many-body : hysics. utshell.	cus is on theorogress and a and gamma methods for response of the course lange cour	oretical aspect applications, decays, Typ	e.g. to ast bes of nuc ar reactio	ear physics, crophysics. lear spectra ns, Nuclear
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The aim of this course is to provide studies introduction to modern nuclear theories when possible, the subject will be linked <b>Course content</b> Introduction to nuclei and nuclear force and EM transitions, Few-body methods astrophysics and formation of the element <b>Literature</b> Text books on nuclear physics, e.g. • Samuel S.M. Wong, Introductory Nucleis Carlos A. Bertulani, Nuclear Physics • Kenneth S. Krane, Introductory Nucleis <b>Entry requirements</b> Recommended prerequisites Language Weighting of the achievement in the	lents wi and to and to l to rece es, Theo s for nu nts. clear Pl in a Nu lear Phy ne over	ith a survey of nu- pics. While the fo ent experimental p ory for alpha, beta iclei, Many-body : hysics. utshell. ysics.	cus is on theorogress and a a and gamma methods for r Course lang Examination 6/120	pretical aspect applications, decays, Typ nuclei, Nucle guage English on language I	e.g. to ast bes of nuc ar reactio	ear physics, crophysics. lear spectra ns, Nuclear
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Modul 746	Module Topical Courses: "Introduction08.12to Lattice Gauge Theory"08.12				28.746	
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods					points	
Lecture with excercises "Introduction to Lattice Gauge Theory" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mu	st be made:			
Presence						
Active participation	accor	ding to §5 subsec	tion 3			
Course achievements		essful completion of		projects		
Module examination	Writ	ten exam (120-180 esentation			(30 Min.),	term pape
Qualification and program goals /	1					
Course content Discretization of PDEs by finite difference QFT; transfer matrix; scalar field theories	es; patl s on the	e lattice and spin r	nodels; Ising n	nodel at high	and low t	emperatur
Course content Discretization of PDEs by finite difference	es; path s on the n and V measu	n integral in quant e lattice and spin r Vegner loop; QED ıre; fermions on t	nodels; Ising n and QCD in t he lattice; sta	nodel at high he continuu tic potentia	and low t m; Wilson l and stro	emperatur loop; lattiong-coupling
Course content Discretization of PDEs by finite difference QFT; transfer matrix; scalar field theories $Z_2$ lattice gauge theory, Elitzur's theorem gauge theory with Wilson action; Haar expansion; renormalization group and co	es; path s on the n and V measu	n integral in quant e lattice and spin r Vegner loop; QED ıre; fermions on t	nodels; Ising n and QCD in t he lattice; sta	nodel at high he continuu tic potentia	and low t m; Wilson l and stro	emperatur loop; lattiong-coupling
Course content Discretization of PDEs by finite difference QFT; transfer matrix; scalar field theories $Z_2$ lattice gauge theory, Elitzur's theorem gauge theory with Wilson action; Haar expansion; renormalization group and co determination of hadronic properties.	es; patl s on the n and V measu ntinuu	n integral in quant e lattice and spin r Vegner loop; QED ıre; fermions on t m limit; lattice pe	nodels; Ising n and QCD in t he lattice; sta rturbation the	nodel at high he continuu tic potentia eory; Monte	and low t m; Wilson l and stro Carlo sim	emperatur loop; latti ong-couplin ulations ar
Course contentDiscretization of PDEs by finite differenceQFT; transfer matrix; scalar field theories $Z_2$ lattice gauge theory, Elitzur's theoremgauge theory with Wilson action; Haarexpansion; renormalization group and codetermination of hadronic properties.Literature• C. Gattringer and C.B. Lang, Quant	es; path s on thu n and V measu ntinuu um Ch	n integral in quant e lattice and spin r Vegner loop; QED ire; fermions on t m limit; lattice pe iromodynamics or	nodels; Ising n and QCD in t he lattice; sta rturbation the	nodel at high he continuum tic potentia eory; Monte (Lect. Notes	and low t m; Wilson l and stro Carlo sim Phys. 788	emperatur loop; latti- ong-couplin ulations ar 8), Springe
<ul> <li>Course content</li> <li>Discretization of PDEs by finite difference</li> <li>QFT; transfer matrix; scalar field theories</li> <li>Z<sub>2</sub> lattice gauge theory, Elitzur's theorem</li> <li>gauge theory with Wilson action; Haar</li> <li>expansion; renormalization group and co</li> <li>determination of hadronic properties.</li> </ul> Literature <ul> <li>C. Gattringer and C.B. Lang, Quant</li> <li>Berlin Heidelberg 2010.</li> <li>J. Smit, Introduction to Quantum F</li> </ul>	es; path s on the n and V measu ntinuu um Ch Fields o	n integral in quant e lattice and spin r Vegner loop; QED ire; fermions on t m limit; lattice pe rromodynamics or	nodels; Ising n and QCD in t he lattice; sta rturbation the the Lattice (	hodel at high he continuu tic potentia cory; Monte (Lect. Notes Cambridge L	and low t m; Wilson d and stro Carlo sim Phys. 788 ect. Note:	emperatur loop; latti- ong-couplin ulations ar 8), Springe
<ul> <li>Course content</li> <li>Discretization of PDEs by finite difference</li> <li>QFT; transfer matrix; scalar field theories</li> <li>Z<sub>2</sub> lattice gauge theory, Elitzur's theorem</li> <li>gauge theory with Wilson action; Haar</li> <li>expansion; renormalization group and co</li> <li>determination of hadronic properties.</li> </ul> Literature <ul> <li>C. Gattringer and C.B. Lang, Quant</li> <li>Berlin Heidelberg 2010.</li> <li>J. Smit, Introduction to Quantum F</li> <li>Cambridge University Press 2002.</li> </ul>	es; path s on the n and V measu ntinuu um Ch Fields o n Field	n integral in quant e lattice and spin r Vegner loop; QED ure; fermions on t m limit; lattice pe nromodynamics or on a Lattice: a ro ls on a Lattice, Ca	nodels; Ising n and QCD in t he lattice; sta rturbation the the Lattice ( obust mate (C ambridge Univ	hodel at high he continuu atic potentia eory; Monte (Lect. Notes Cambridge L versity Press	and low t m; Wilson l and stro Carlo sim Phys. 788 ect. Notes 1994.	emperatur loop; latti- ong-couplin ulations ar 8), Springe s Phys. 15
<ul> <li>Course content</li> <li>Discretization of PDEs by finite difference</li> <li>QFT; transfer matrix; scalar field theories</li> <li>Z<sub>2</sub> lattice gauge theory, Elitzur's theorem</li> <li>gauge theory with Wilson action; Haar</li> <li>expansion; renormalization group and co</li> <li>determination of hadronic properties.</li> </ul> Literature <ul> <li>C. Gattringer and C.B. Lang, Quant Berlin Heidelberg 2010.</li> <li>J. Smit, Introduction to Quantum F</li> <li>Cambridge University Press 2002.</li> <li>I. Montvay and G. Münster, Quantur</li> </ul>	es; path s on the n and V measu ntinuu um Ch Fields o n Field	n integral in quant e lattice and spin r Vegner loop; QED ure; fermions on t m limit; lattice pe nromodynamics or on a Lattice: a ro ls on a Lattice, Ca	nodels; Ising n and QCD in t he lattice; sta rturbation the the Lattice ( obust mate (C ambridge Univ	hodel at high he continuu atic potentia eory; Monte (Lect. Notes Cambridge L versity Press	and low t m; Wilson l and stro Carlo sim Phys. 788 ect. Notes 1994.	emperatur loop; latti- ong-couplin ulations ar 8), Springe s Phys. 15
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Modul 760	Module Topical Courses: "Introduction08.128.760to String Theory"08.128.760					
Compulsory or elective module	WP					
Credit points and workload	6 LP	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	time	study	points
Lecture with excercises "Introduction to String Theory" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ing a	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsecti	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination		en exam (120-180 esentation	Min.), oral ex	xamination (	(30 Min.), t	erm paper
Qualification and program goals /	Comp	etences				

The lectures' program goal is to provide a basic understanding of classical and quantised bosonic and fermionic string theories. An additional goal is to teach methods which are required for the maters's thesis.

### Course content

Classical bosonic string, quantisation (lightcone, covariant, path integral, BRST formalism), D-branes, superstrings, introduction to conformal field theory, string amplitudes.

### Literature

various textbooks, publications close to science, e.g.:

- Zwiebach: A First Course in String Theory, Cambridge University Press 2004;
- Blumenhagen, Lüst, Theisen: Basic Concepts of String Theory, Springer 2012;
- Polchinski: String Theory, Vol. 1 & 2, Cambridge University Press 1998;
- Green, Schwarz, Witten: String Theory, Vol. 1 & 2, Cambridge University Press 1987;
- Becker, Becker, Schwarz: String Theory and M-Theory A Modern Introduction, Cambridge University Press 2007

Entry requirements	
Recommended prerequisites	
Language	Course language English
Language	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Irregular
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. G. Honecker
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 766	Module Topical Courses: "Effective Field08.128.766Theories"08.128.766					
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	$\mathbf{time}$	study	points
Lecture with excercises "Effective Field Theories" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	st be made:			
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	successful completion of exercises or projects					
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (	$(30 \text{ Min.}), \uparrow$	term paper
Qualification and program goals /	Comp	etences				
The lectures introduce the basic ideas of	the eff	ective field theory	approach like	relevant and	d irrelevant	operators.

The lectures introduce the basic ideas of the effective field theory approach like relevant and irrelevant operators, renormalization group, decoupling of heavy particle. The lectures also provide a deeper understanding of its most important applications in modern research fields.

### Course content

The method of effective field theory provides a systematic approach to multi-scale problems. An effective field theory uses the appropriate degrees of freedom to describe the phenomena at a given energy scale, while all degrees of freedom only relevant at much higher scales are eliminated from the theory. These concepts lead to a large variety of phenomenological applications in modern particle physics. Especially in the theory of strong interactions with its different behaviour at the various energy scales the important examples of the electroweak Lagrangian, heavy-quark-effective theory, and soft-collinear-effective theories allow for most suitable descriptions of the respective theoretical systems.

- Lecture notes Ëffective Field Theory"by A. Pich
- Lecture notes Ëffective Field Theories" by A. Manohar
- Lecture notes Ëffective Field Theories and Heavy Quark Physics" by M. Neubert

Entry requirements	
Recommended prerequisites	
Language	Course language English
Language	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Irregular
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. M. Neubert
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 762	Module Topical Courses: "Theoretical 08.128 Astroparticle Physics"					28.762
Compulsory or elective module	WP					
Credit points and workload	6 LP = 180 h					
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	${f Self} \ {f study}$	Credit points
Lecture with excercises "Theoretical Astroparticle Physics" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			$3 \; \mathrm{SWS}$		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ac	chievements mu	st be made:		•	
Presence						
Active participation	accor	ding to §5 subsect	ion 3			
Course achievements	succe	ssful completion o	f exercises or	projects		
Module examination		successful completion of exercises or projectsWritten exam (120-180 Min.), oral examination (30 Min.), term or presentation				term paper
Qualification and program goals / This lecture aims to give, from a theor astroparticle physics. Its goal is to prepa dark matter, neutrinos and related topic	rists po are stud s and t	etences bint of view, a bro lents to understan o prepare them for	d the current	scientific lite	erature on	cosmology,
This lecture aims to give, from a theor astroparticle physics. Its goal is to prepa dark matter, neutrinos and related topic experimental or theoretical astroparticle	rists po are stud s and t	etences bint of view, a bro lents to understan o prepare them for	d the current	scientific lite	erature on	cosmology,
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Modul 764	Module Topical Courses: "Amplitudes and Precision Physics at the LHC"08.128.					8.764
Compulsory or elective module	WP					
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty- pe	Designated term	Degree of obligation	Contact time	Self study	Credit points
Lecture with excercises "Amplitudes and Precision Physics at the LHC" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving a	chievements mus	t be made:			
Presence						
Active participation	accor	ding to §5 subsecti	on 3			
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination		ten exam (120-180 esentation	Min.), oral e	xamination (3	30 Min.),	term pape
Qualification and program goals /	Comp	etences				
Course content Spin- and helicity methods, colour decortering equations; loop integrals, different						
polylogarithms).						
Literature						
• J. Henn, J. Plefka, "Scattering Ampl	itudes	in Gauge Theories'	, Springer, 2	014;		
• H. Elvang, Y. Huang, "Scattering A: 2015;	mplituo	les in Gauge Theo	ry and Grav	ity", Cambrid	lge Unive	naite Duga
	1. 1					rsity Pres
• L. Dixon, "Calculating Scattering An	nplitud	es Efficiently", arx	iv.org/abs/he	ep-ph/960135	9	rsity ries
Entry requirements	nplitud	es Efficiently", arx	iv.org/abs/he	ep-ph/960135	9	
Entry requirements		es Efficiently", arx				rsity Pres
Entry requirements Recommended prerequisites Language	- 		Course lang Examinatio	ep-ph/960135 guage English on language F	1	
Entry requirements Recommended prerequisites Language Weighting of the achievement in th	- 		Course lang Examination 6/120	guage English	1	
Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency	le ovei		Course lang Examinatio	guage English	1	
Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	le over		Course lang Examinatio 6/120 Irregular	guage English on language E	ı Ənglish or	German
Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance Persons responsible for this module	e over		Course lang Examinatic 6/120 Irregular Prof. Dr. J	guage English on language F . Henn, Prof.	ı Ənglish or	German
Entry requirements Recommended prerequisites Language Weighting of the achievement in the Module frequency Reasons for compulsory attendance	e over		Course lang Examinatic 6/120 Irregular Prof. Dr. J M.Sc. Phys	guage English on language F . Henn, Prof.	n English or Dr. S. W	German

Course language: English

Miscellaneous

Modul 747	Module Topical Courses: "Functional Methods and Exact Renormalization Group"08.128.747					8.747
Compulsory or elective module	WP				·	
Credit points and workload	6 LF	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	$\operatorname{time}$	$\mathbf{study}$	points
Lecture with excercises "Functional Methods and Exact Renormalization Group" (WP)		1	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	wing achievements must be made:					
Presence						
Active participation	accor	ding to §5 subsecti	ion 3			
Course achievements	succe	ssful completion of	f exercises or	projects		
Module examination		ten exam (120-180 esentation	Min.), oral ex	xamination (	30 Min.), t	erm paper

### Qualification and program goals / Competences

The goal of this lecture is to introduce students to path integrals, functional integral quantization of field theories and the functional renormalization group equation.

### Course content

(A) Path integrals in quantum mechanics:

- Relation to the canonical approach, discretization and operator ordering, topological aspects (multiply connected configuration spaces, etc.), evaluation of functional integrals (exactly soluble examples, semiclassical expansion, perturbation theory), instantons in quantum mechanics (double well, periodic potentials, n- and Theta-vacua).
- (B) Functional integral quantization of field theories:
- Functional Schroedinger picture, wave functionals, field-particle relationship, symmetry and covariance properties, from transition amplitudes to (vacuum-) correlators and generating functionals, the Schwinger-Symanzik approach, functional integral representation via the Schroedinger picture and the Schwinger-Symanzik approach, the effective action (canonical and diagrammatic approaches, Legendre-Fenchel transform), computational techniques (semiclassical and perturbative expansion), perturbative Yang-Mills theory, nonperturbative Yang-Mills theory ("large"gauge transformations, homotopy classes- and groups, instantons and tunneling, nonperturbative vacuum structure).
- (C) The functional renormalization group equation (FRGE):
- Functional (i.e. "exact") vs. perturbative renormalization, critical phenomena, Wilsonian renormalization group in statistical mechanics and quantum field theory (theory space, block spin transformations, coupling constant flows), notions of nonperturbative renormalizability, continuum limits and phase transitions, construction and "solution" of quantum field theories by means of FRGE methods.

Entry requirements	
Recommended prerequisites	
Language	Course language English
	Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Irregular
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. M. Reuter
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English

Modul 806	Mod Part	ule Topical icle Physics"	Courses:	"Advance	d 08.12	28.806
Compulsory or elective module	WP					
Credit points and workload	6 LP	= 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	pe	term	obligation	time	study	points
Lecture with excercises "Advanced Par-		2	Р		138 h	6 LP
ticle Physics" (WP)						-
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ac	hievements mu	st be made:			
Presence						
Active participation		ling to §5 subsect				
Course achievements		sful completion c				
Module examination	Writte	en exam (90-180 )	Min.) or oral	examination	(30  Min.)	
The newest experimental methods and recourse provides the students with advat thesis in a related research area.						
<ul> <li>course provides the students with advattation of the search area.</li> <li>Course content</li> <li>The content of the course is variable and</li> <li>Lepton scattering at high energies,</li> <li>Strong interaction,</li> <li>Electro-weak interaction, as well as</li> <li>Models for the unification and extrement</li> </ul>	nced kn 1 will ty	owledge that will pically include on	l help in com	pleting an e	experiment	
<ul> <li>course provides the students with advattation and thesis in a related research area.</li> <li>Course content</li> <li>The content of the course is variable and</li> <li>Lepton scattering at high energies,</li> <li>Strong interaction,</li> <li>Electro-weak interaction, as well as</li> </ul>	nced kn 1 will ty	owledge that will pically include on	l help in com	pleting an e	experiment	
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<ul> <li>course provides the students with advatt thesis in a related research area.</li> <li>Course content</li> <li>The content of the course is variable and</li> <li>Lepton scattering at high energies,</li> <li>Strong interaction,</li> <li>Electro-weak interaction, as well as</li> <li>Models for the unification and extrem</li> <li>Literature</li> <li>C. Berger, Elementarteilchenphysik</li> <li>D. Griffiths, Introduction to Elementarteilchenphysik</li> </ul>	nced kn l will ty sion of ary Par	pically include on the Standard Mo	l help in com ne of the follo del.	pleting an e	s:	
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Modul 807	Modu Chap	ule Topical oters on Subat		"Advance ics"	ed 08.12	28.807
	<b>r</b>					
Compulsory or elective module	WP					
Credit points and workload	6 LP	= 180 h				
<b>Duration</b> according to the study plan	1					
	Ty-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	time	study	points
Lecture with excercises "Advanced Chapters on Subatomic Physics" (WP)		2	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	-	nievements mu	st be made:	1000		
Presence			Ju be made.			
Active participation	accord	ing to §5 subsect	ion 3			
Course achievements		sful completion o		projects		
Module examination		n exam (90-180 ]			(30 Min )	1
Qualification and program goals /		`			(00 11111)	
The lecture intends to provide a deep u cepts as well as research topics will be p successfully complete an experimental m	presented	d. The lecture wi	ll provide the			
The lecture intends to provide a deep u cepts as well as research topics will be p	nagnetic na of had	d. The lecture with thesis in related for and hadronic pr drons; effective t	ll provide the ields. obes, polariza heories; spect	e essential ki ution experir roscopy, sym	nowledge n nents; reso nmetry an	necessary to onances, de- d structures
The lecture intends to provide a deep us cepts as well as research topics will be p successfully complete an experimental m <b>Course content</b> Current experimental methods, electrons cays, form factors and structure function of hadrons, the impact of hadron physic	nagnetic na of had	d. The lecture with thesis in related for and hadronic pr drons; effective t	ll provide the ields. obes, polariza heories; spect	e essential ki ution experir roscopy, sym	nowledge n nents; reso nmetry an	necessary to onances, de- d structures
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The lecture intends to provide a deep uselepts as well as research topics will be presuccessfully complete an experimental methods, electrons cays, form factors and structure function of hadrons, the impact of hadron physic discussed for all topics.          Literature         Several text books, e.g.         • B. Povh et al., Teilchen und Kerne         • D. H. Perkins, High Energy Physics         • W. Thomas und W. Weise, The Struct         Entry requirements         Recommended prerequisites         Language         Weighting of the achievement in the         Module frequency         Reasons for compulsory attendance	cture of	d. The lecture with the Nucleon	ll provide the ields. obes, polariza heories; spect the Standard Course lang Examinatio 6/120	e essential ka ation experir roscopy, sym Model. Key guage Englis on language i Denig	nowledge n ments; reso nmetry an y experim	necessary to onances, de- d structures ents will be

Modul 808	Module Topical Courses: Astroparticle- and Astrophy			"Advance sics"	d 08.12	28.808
Compulsory or elective module	WP				•	
Credit points and workload	6 LP	= 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods		Designated term	Degree of obligation	Contact time	${f Self} \ {f study}$	Credit points
Lecture with excercises "Advanced Astroparticle- and Astrophysics" (WP)		2	Р		138 h	6 LP
Lecture (WP)	V			3 SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving ach	nievements mu	st be made:			
Presence						
Active participation	accordi	ing to §5 subsect	ion 3			
Course achievements	success	sful completion o	f exercises or	projects		
Module examination	Writter	n exam (90-180 ]	Min.) or oral	examination	(30 Min.)	
Qualification and program goals /	Compet	tences				
This course covers special aspects of as perimental methods and results. The co- completing an experimental master's the	tropartic ourse pro	cle physics and a ovides the stude	nts with adva			
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Modul 816	Module Topical Courses: "Advanced Ac- celerator Physics"08.128.816					8.816
Compulsory or elective module	WP					
Credit points and workload	6 LP	P = 180 h				
<b>Duration</b> according to the study plan	1					
Courses and teaching methods	Ту-	Designated	Degree of	Contact	Self	Credit
Courses and teaching methods	ре	term	obligation	$\operatorname{time}$	study	points
Lecture with excercises "Advanced Ac- celerator Physics" (WP)		2	Р		138 h	6 LP
Lecture (WP)	V			3  SWS		
Excercises (WP)	Ü			1 SWS		
To complete the module, the follow	ving achievements must be made:					
Presence						
Active participation	according to §5 subsection 3					
Course achievements	succe	ssful completion of	exercises or	projects		
Module examination	Writt	en exam (90-180 N	In.) or oral	examination	(30 Min.)	
Qualification and program goals /	Comp	etences				

The first objective of the course is to understand spin-polarized ensembles. Later-on, we will discuss their behavior under the conditions of relativistic motion in macroscopic external fields. This regime is governed by the Thomas-BMT equation. The spin dynamics in spin rotators, recirculating linear accelerators, but also in particular for synchrotrons and storage rings will be discussed. The second part is devoted to the realization of spin-sensitive experiments at accelerators which are of course based on the interaction of spins with microscopic fields. Information on these interactions may be obtained by measuring spin sensitive observables, e.g. the analysing power of the process. The presentation of experimental techniques such as polarized sources and polarimeters concludes the course. The course provides the background to successfully complete a master's thesis in the groups at MAMI that deal with experiments based on spin-polarized beams.

### Course content

The course will provide knowledge and competence with respect to the following subjects: Spin polarized ensembles, density matrix, Dirac' equation, spin precession in the lab frame (Thomas BMT equation), single pass spin rotators, sibirian snakes, intrinsic and imperfection resonances in storage rings, Sokolov-Ternov effect, spinstable solutions, depolarization by synchrotron radiation, spin equilibrium, spin polarized sources, spin sensitive observables (analyzing powers), polarimetry parity violating observable, Parity violation experiments at accelerators, double polarization experiments with polarized targets at collider facilities.

- D. Barber: Introduction to Spin polarisation in accelerators and storage rings
- B.W. Montague Physics Reports 113 (1984) 1-96
- A. Lehrach: Strahl und Spin-Dynamik von Hadronenstrahlen in Mittelenergiespeicherringen. Schriften des Forschungszentrums Jülich, Reihe Schlüsseltechnologien, Jülich 2008 ISBN 978-3-89336-548-7

Entry requirements	
Recommended prerequisites	
Language	Course language English Examination language English or German
Weighting of the achievement in the overall grade	6/120
Module frequency	Every summer semester
Reasons for compulsory attendance	
Persons responsible for this module	Prof. Dr. K. Aulenbacher
Applicable to the following programs	M.Sc. Physics
Miscellaneous	Course language: English