Physical Sciences

MSc, Integrated PhD Program

Contents

Disclaimer

As of September 1, 2014 the School of Engineering and Science and the School of Humanities and Social Sciences have been replaced by the Focus Areas Health, Mobility and Diversity. Handbooks and policies might still refer to the old structure of Schools.

If this is the case, references to the School of Engineering and Science include courses offered within the following disciplines:

- Electrical Engineering and Computer Science
- Life Sciences
- Logistics
- Mathematical Sciences
- Natural and Environmental Sciences

References to the School of Humanities and Social Sciences include courses offered within the following disciplines:

- Economics and Management
- History
- Humanities
- Law
- Psychology
- Social Sciences
- Statistics and Methods

1 General Information

1.1 Physical Sciences

The Physical Sciences program encompasses the study of physics, chemistry, and the emerging field in between, nanoscience. The unifying research themes are the physical and chemical properties of material within the context of theory, design, and experiment. The program is open to related fields of research, including promising areas such as biophysics.
The physical sciences are the foundation for understanding and improving many aspects of our daily lives. For example, as societies and individuals, we are highly dependent on products and technologies that were conceptualized and developed using the principles of physics, chemistry, and nanoscience. Relevant examples are the fabrication of nanoparticles enabling the next generation of devices, supramolecular assemblies that mimic nature's raw but highly controlled power, and drug design and delivery for disease inhibition. At the same time, researchers in the physical sciences trace the evolution of the universe, hunt for elusive sub-atomic particles, and design sensors for identifying toxins and explosives.
The present Physical Sciences Graduate Program consists of three tracks. The track "Physics" enables a broad study of the physical foundations of eminent problems, Physics forms the basis of our understanding of objects as diverse as elementary particles, molecules, living cells, electronic devices, stars and galaxies. The "Chemistry" track provides a diverse spectrum to study, from catalysis, to drug design, to supramolecular structures whether they be organic or inorganic in origin. The track "Nanoscience" deals with problems at the nanometer length scale where the traditional sciences of physics, chemistry and biology loose their distinctiveness and merge into a new transdisciplinary science, commonly known as "Nanoscience" and its concomitant technology.
Since the studies of "Chemistry", "Physics" and "Nanoscience" have many common features and foundations, they have been combined in the Physical Sciences Graduate Program to allow for synergistic effects in both, teaching and research. At Jacobs University Bremen the Physical Sciences Graduate Program is supported mainly by the Focus Area Health and the Mathematics, Modeling, and Computing Research Center MAMOC. But also other centers such as the Molecular Life Science Research Center MOLIFE are connected to this graduate program. Details on the faculty involved in the Physical Sciences Graduate program and their respective research topics can be found at `http://www.jacobs-university.de/ses/physical-sciences`.

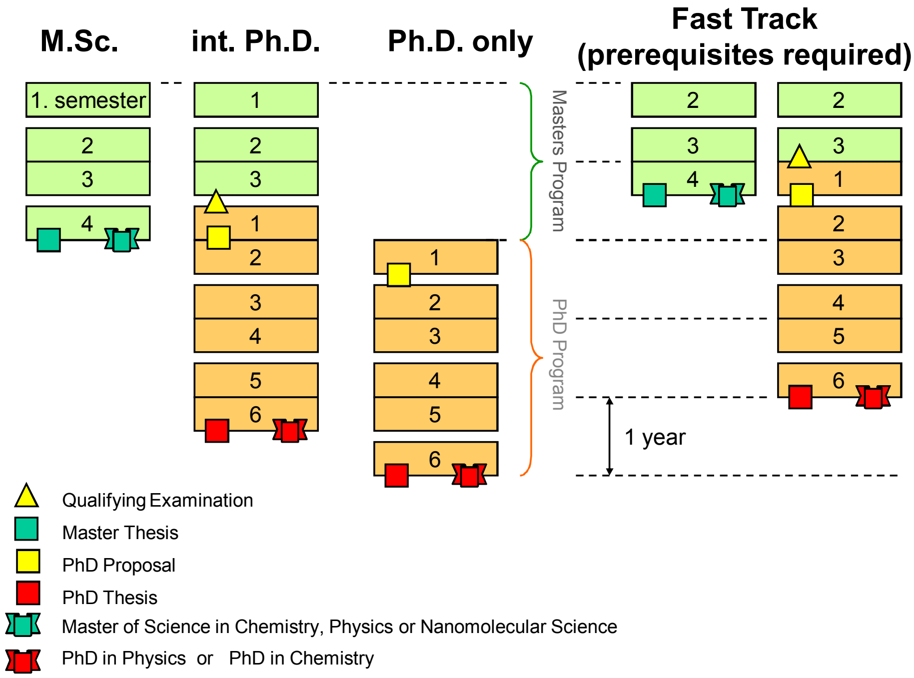
1.2 General Structure

In all tracks, the "Physics", "Chemistry" as well as the "Nanoscience" track, the graduate program offers different options and degrees.
M.Sc. studies contain course work (3 semesters, 9 courses, and further seminars and research) and a Master Thesis in the 4^{th} semester. Courses are designed to provide a broad education in physics, chemistry, and nanoscience including their applications. The 2-year program leads to a M.Sc. in Chemistry, Physics or Nanomolecular Science and importantly includes a rewarding research component.
Integrated Ph.D. studies include the same course phase as the M.Sc. studies (3 semesters). Thereafter the students progress from the M.Sc. studies to the Ph.D. program by passing a Qualifying Exam (usually before the 4th semester of the Master's Program). An M.Sc. thesis

is not required. Thereafter the students proceed with the Ph.D. studies outlined below. After eight months of Ph.D. study, a proposal is submitted and defended.

Ph.D. studies are performed under the supervision of a faculty member within the Physical Science graduate program, and provide independent and in-depth research experiences with an emphasis on problem-solving skills. Our programs have a strong research orientation, but also include academic events such as seminars and colloquia, which all Graduate Students participate in on a regular basis. The 3-year program awards a Ph.D. in Chemistry or a Ph.D. in Physics.

A **Fast Track option** exists for qualified students. To be eligible for this option, some of the graduate track courses will have already been completed. This most often applies to Jacobs University undergraduate students who take these courses above and beyond (cannot count toward your undergraduate credits) their normal course load.



Note: A successfully passed Qualifying Examination and Ph.D. Proposal does not automatically imply Jacobs University funding during the 3-year Ph.D. Program following the course phase. For Ph.D. studies the choice of faculty member may be restricted by limits to those Ph.D. supervisors with available funding.

1.3 Prospects for Graduates/Career Options

The Physical Sciences Graduate Program is inherently cross-disciplinary, probably more so than many other areas of research. It has an impact on a very broad range of industries and technologies, including the chemical, pharmaceutical, biotechnology, semiconductor and computer industries, as well as environmental, energy, information, materials and medical technologies. The program is firmly embedded in the interdisciplinary research cooperations within Jacobs University and with various external partners, academic and commercial. These opportunities provide our graduates with the high caliber training sought after by potential employers.

While Jacobs University's graduate program in Physical Sciences will certainly equip students for careers at the frontiers of research and development in universities, research institutes and company laboratories, almost all of these employers also need trained graduates for positions in law (patent and court), administration, technical support, service, and sales, to name but a few examples. Finally, the fact that graduates of the program have learned to communicate with specialists from different fields is a highly relevant qualification in many consulting, policy-making, administration, and governmental jobs. In an increasingly technology-driven world, individuals in decision-making positions need to have sound knowledge on diverse topics such as computers and microelectronics, chemical technology, energy resources and sustainability, all of which are touched upon by an education such as Jacobs University's graduate program in Physical Sciences.

Fig.: Research in the femtosecond laser lab at Jacobs University.

Chemistry Track

with

Ph.D. in Chemistry

and

M.Sc. in Chemistry

2 Chemistry Track

2.1 Concept

2.1.1 Chemistry

Chemistry is the molecular basis of all science, including biology and physics. It is required for the design, synthesis, isolation, and application of small and large molecules in biochemistry and molecular biology that permit the detection and treatment of diseases. It is indispensible for the construction of new functional materials for applications in, e.g., fuel cells, light-emitting diodes, and plastics. Furthermore Chemistry provides the fundamental tools allowing for the analysis of plant constituents, environmental pollutants, and metabolites among many other examples.

2.1.2 Scope of the Chemistry Track

The Chemistry track aims at bridging the gap between the knowledge about small molecules and the understanding of larger assemblies. On another level, it expands your knowledge regarding the design, synthesis, and application of molecules of consequence, i.e., those with unique properties. A further focus is on the elucidation of compounds in natural products and food. Students will be exposed to this material in variety of courses, e.g., Supramolecular Chemistry, Quantum Chemistry, Organocatalysis, and Experimental Techniques. Here, and in alternative courses, you will be provided with the relevant theoretical and experimental tools to broaden your understanding of current challenges in chemistry. A strong component of your degree will be research oriented. To jump start this process you will participation in the research of three different groups during your first semester. This experience will aid your ability to find a research group compatible with your long term interests. The Chemistry Track is further distinguished by the following features:

- Strong focus on learning in a research context class room) and via 'hands on' research projects (laboratory or computational setting)
- Interdisciplinary research
- Choice of elective courses from chemistry, physics, and biochemistry/biotechnology to suit the individual interests and background of the student

The chemistry faculty, forming the backbone of the teaching staff, is highly active in research and in this respect ranks among the highest of the German universities.

2.1.3 Target Group

The program is aimed at students with an excellent record in undergraduate chemistry or closely related subjects (chemical engineering, material science, biochemistry, biotechnology, physical chemistry). A very good working knowledge of English is mandatory. A minimum of four chemistry courses is highly desirable.

2.2 Graduation Requirements for the Chemistry Track

2.2.1 Course Work Requirements

90 ECTS from lectures, practical training and seminars

2.2.2 Graduation Requirements for M.Sc. in Chemistry

Successful completion of course work, practical training, and seminars plus 30 ECTS for independent research and approved Master thesis. The course work consists of

- mandatory lectures: Supramolecular Chemistry, Introduction to Computational Chemistry including laboratory, Nanomolecular Science, and Experimental Techniques (20 ECTS)
- mandatory practical training: Physical Sciences Research Methods, Physical Sciences Advanced Guided Research I & II (30 ECTS)
- mandatory seminars: Current Topics in Physical Sciences, Physical Sciences Graduate Seminar I & II (15 ECTS)
- elective courses: see final chapter for a list of courses (25 ECTS)

Each course can only be counted once towards one of the M.Sc. or Ph.D. degrees offered in the program.

During the first three semester, 90 ECTS credit points for course work need to be accumulated. Out of this 90 ECTS points, 60 ECTS points are for lectures as well as seminars and 30 ECTS points for practical training and research. In case of an M.Sc. study, additional 30 ECTS points for Independent Research and the M.Sc. thesis in the fourth semester are mandatory.
Up to 20 ECTS credit points of the electives can be substituted by suitable graduate courses from other graduate programs at Jacobs University, certain 3rd year undergraduate specialization courses or courses in the framework of joint graduate schools with external universities. The latter courses might be offered as block courses in some cases. Substitutions are subject to approval by the Graduate Advisor and Program Coordinator. 3rd-year courses may only be credited if they have not been credited towards their undergraduate degree. Students can take additional courses (lectures, labs, seminars; within or outside the Physical Sciences graduate program; graduate or undergraduate level) in order to broaden or deepen their field of study.

2.2.3 Graduation Requirements for Integrated Ph.D.

- Promotion to Ph.D. phase: Successful completion of course work plus qualifying exam.
- Qualifying Examination: Oral (or written) exam on Nanomolecular Science, Quantum Chemistry, and Supramolecular Chemistry, and one elective. The selection has to be discussed with the Academic Advisor and communicated to the Program Coordinator. In agreement with the Graduate policies, the Qualifying Examinations in Integrated Ph.D. Programs take place before the beginning of the fourth semester, assuming that the student has completed the coursework requirements. In case of an oral exam, at least three faculty members must be present, and the typical duration is no less than one hour. The Qualifying Examination has the outcome “pass” or “fail”.
- Requirements for Ph.D.: Admission to Ph.D. phase, approved Ph.D. proposal (proposal and oral defense), Ph.D. thesis and successful defense.

- Ph.D. proposal: Every student needs to develop a written Ph.D. proposal incl. research plan in cooperation with his Ph.D. Advisor. It has to be presented in public upon invitation by the Dean at most eight months after the qualifying exam or after entrance into the Ph.D. Program. The presentation of about 30 minutes should be followed by an oral defense of 30-60 minutes. The Dissertation Committee approves the Ph.D. Proposal. In exceptional cases, students might combine the Ph.D. proposal with an M.Sc. thesis in one document. This needs to be discussed in detail with and approved by the Graduate Advisor as well as the Program Coordinator.
- Ph.D. defense: After approval of the Ph.D. thesis, the candidate need to present his research in a presentation of 30-40 minutes followed by an oral defense of 45-90 minutes. The Dissertation Committee approves the Defense.
- Publication of Ph.D. thesis

Any adjustments/amendments need to be discussed with the Program Coordinator. For further details please also see the Graduate Policies of the Jacobs University and the accompanying guidelines.

2.2.4 Graduation Requirements for Ph.D. only

- The requirements for a Ph.D. include the admission to the Ph.D. phase, an approved Ph.D. proposal, an approved Ph.D. thesis, successful defense as well as publication of the PhD thesis. The details are the same as described above. Please also see the Graduate Policies of Jacobs University and the accompanying guidelines.

2.3 Recommended Course Plan: Chemistry Track

Semester 1 Courses	Course Number	C	T
Experimental Techniques	420542	5	m
Introduction to Computational Chemistry		2.5	m
Introduction to Computational Chemistry - Laboratory		2.5	m
Physical Sciences Research Methods	420421	10	m
Current Topics in Physical Sciences	420472	5	e
Elective Course (see final section for a list of courses)		5	e
Semester 2 Courses	**Course Number**	**C**	**T**
Nanomolecular Science	420431	5	m
Supramolecular Chemistry	420432	5	m
Physical Sciences Graduate Student Seminar I	420412	5	m
Physical Sciences Advanced Guided Research I	420462	10	m
Elective Course		5	e
Semester 3 Courses	**Course Number**	**C**	**T**
Physical Sciences Graduate Student Seminar II	420511	5	m
Physical Sciences Advanced Guided Research II	420461	10	m
Elective Course		5	e
Elective Course		5	e
Elective Course		5	e
Semester 4 Courses (M.Sc. only)	**Course Number**	**C**	**T**
Physical Sciences Independent Research and M.Sc. thesis	420522	30	m

C = ECTS credit points, T=type (m=mandatory, e=elective)

Note:

1. Research Methods, Advanced Guided Research and M.Sc. Thesis comprises work in one or more experimental research labs or theory groups at Jacobs University on topics of current interest. A written M.Sc. thesis (40 pages suggested) and an oral presentation of the results are required. Students should contact faculty regarding a research topic.

Recommendation Professional Skills

The SES highly recommends attending the Professional Skills seminars offered by the Career Services Center. Those seminars include soft skills development seminars and application trainings which will help you cope with your studies and master internship and job search.

Further details can be found at the Teamwork server of the university at
https://teamwork.jacobs-university.de/confluence/display/APS

Physics Track

with

Ph.D. in Physics

and

M.Sc. in Physics

3 Physics Track

3.1 Concept

3.1.1 Physics

Physics builds the foundation of the natural sciences and many engineering disciplines. It forms the basis of our understanding of objects as diverse as elementary particles, molecules, living cells, electronic devices, stars and galaxies. Their behavior and properties are governed by the same universal physical principles which are the central topics of any physics curriculum. Our society was shaped and will be shaped in the future by the emergence of new technologies (e.g., electrical power, information technology, nanotechnology) and by new insights from where we come and in which world we live (evolution, relativity, quantum mechanics, cosmology). Physics always has and will also in the future contribute to a better understanding of the world around us and improve our daily life by providing the basis for new technologies. Physics is also an experimental science and every theory or model of the world has to be verified by experimental evidence. For a physical understanding of natural phenomena in the world around us both approaches are necessary, a theoretical and abstract description of general principles but also the experimental knowledge how to obtain and analyse experimental data. With a M.Sc. or Ph.D. in physics students can contribute to advance the knowledge in different areas of science and engineering, or by solving problems related to challenges of global importance such as:

- What is the microscopic description of space, time and matter that is consistent with quantum physics and gravity?
- What will be the most effective future energy source and energy storage technology?
- What physical principles and methods can be used to develop new materials?
- How can we investigate and explain the motion of electrons on femtosecond time-scales?
- How can we understand the transport of antibiotics across membranes to develop new drugs against ever more resistant bacteria?

Research at the beginning of the 21st century concentrates on the investigation of small scale structures (quantum gravity, nanotechnology), large scale structures (astrophysics, cosmology), new materials discovered in interdisciplinary research, and complex systems requiring computational or new mathematical approaches.

3.1.2 Scope of the Physics Track

The Physics track in the Physical Sciences graduate program builds on a broad and general B.Sc. in physics and leads to a further specialization and deeper insight in specific areas which is necessary to contribute to international competitive research. During the course work an emphasis is put on a balanced ratio of experimental, theoretical and applied physics with a strong research component. The core courses (quantum mechanics, statistical physics, field theory, condensed matter) build the backbone of the program track whereas by electives and specialization courses the individual preferences of students are taken into account. The primary areas of research and specialized teaching in physics at Jacobs University are material science and condensed matter physics, computational and experimental biophysics, theoretical and mathematical physics, and astrophysics. Especial emphasis is given on cross-disciplinary research and the overlap of physics with the life sciences, chemistry, mathematics, and astronomy.

Some distinguishing points of the physics program track at Jacobs are:

- Strong focus on research and independent scientific work - starting in the first year
- Broad range of expertise and research interests of faculty to foster transdisciplinarity
- Exposure of students to substantial computational components
- Internationality, English as primary language for instructions and administration
- Possible choice of elective courses from other graduate programs connected to the Focus Areas Health and Mobility such as the Research Center for “Mathematics, Modeling, and Computing (MAMOC)”, “Molecular Life Science Center (MOLIFE)” and the DFG Research Training Group “Models of Gravity”.

More than ten Physics faculty members contribute to teaching of the physics track in the Physical Sciences graduate program and conduct active research in the fields of condensed matter, laser physics, biophysics, classical and quantum gravity, mathematical and statistical physics and many other topics. Many of these subjects are both tackled from the side of theoretical as well as experimental physics. The research of faculty is supported by numerous postdoctoral fellows and students.

3.1.3 Target Group

The program is intended for national and international students with an excellent record in undergraduate physics or a closely related subject (e.g., physical chemistry, material science, ...). Since English is the primary language on campus, a very good working knowledge of English to read and discuss scientific topics is a mandatory prerequisite for students enrolling in the program. Applicants for the graduate physics track should have already experienced physics research in their undergraduate studies, and are now keen to extend their physics background and deepen their knowledge in a specific area of physics. To do so a certain level of curiosity paired with analytical-mathematical thinking, but also persistence and structured working are necessary. For students interested in the integrated Ph.D. option an additional academic set of mind, scientific creativity and enthusiasm for hard work and independent research is a further requirement.

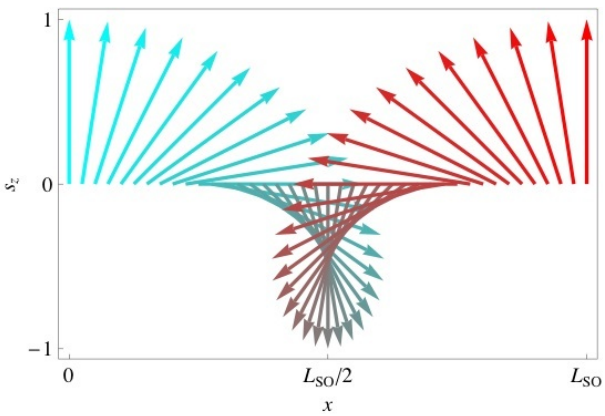


Fig.: Spintronics, the manipulation of the electron spins for energy efficient storing and transport of information, requires a detailed understanding of spin dynamics and transport.

3.2 Graduation Requirements for the Physics Track

3.2.1 Course Work Requirements

90 ECTS from lectures, practical training and seminars

3.2.2 Graduation Requirements for M.Sc. in Physics

Successful completion of course work, practical training, and seminars plus 30 ECTS for independent research and approved Master thesis. The course work consists of

- three out of the following four lectures: Advanced Quantum Mechanics, Advanced Statistical Physics, From Molecules to Matter and Classical and Quantum Field Theory (15 ECTS)
- mandatory practical training: Physical Sciences Research Methods, Physical Sciences Advanced Guided Research I & II (30 ECTS)
- mandatory seminars: Current Topics in Physical Sciences, Physical Sciences Graduate Seminar I & II (15 ECTS)
- elective courses: see final chapter for a list of courses (30 ECTS)

Each course can only be counted once towards one of the M.Sc. or Ph.D. degrees offered in the program.

During the first three semester, 90 ECTS credit points for course work need to be accumulated. Out of this 90 ECTS points, 60 ECTS points are for lectures as well as seminars and 30 ECTS points for practical training and research. In case of an M.Sc. study, additional 30 ECTS points for Independent Research and the M.Sc. thesis in the fourth semester are mandatory.
Up to 20 ECTS credit points of the electives can be substituted by suitable graduate courses from other graduate programs at Jacobs University, certain 3rd year undergraduate specialization courses or courses in the framework of joint graduate schools with external universities. The latter courses might be offered as block courses in some cases. Substitutions are subject to approval by the Graduate Advisor and Program Coordinator. 3rd-year courses may only be credited if they have not been credited towards their undergraduate degree. Students can take additional courses (lectures, labs, seminars; within or outside the Physical Sciences graduate program; graduate or undergraduate level) in order to broaden or deepen their field of study.

3.2.3 Graduation Requirements for Integrated Ph.D.

- Promotion to Ph.D. phase: Successful completion of course work plus qualifying exam.
- Qualifying Examination: Oral (or written) exam on three of the four core topics and one elective. The four core topics are quantum mechanics, statistical physics, condensed matter physics, as well as classical and quantum field theory. The selection has to be discussed with the Academic Advisor and communicated to the Program Coordinator. In agreement with the Graduate policies, the Qualifying Examinations in Integrated Ph.D. Programs take place before the beginning of the fourth semester, assuming that the student has completed the coursework requirements. In case of an oral exam, at least three faculty members must be present, and the typical duration is no less than one hour. The Qualifying Examination has the outcome “pass” or “fail”.
- Requirements for Ph.D.: Admission to Ph.D. phase, approved Ph.D. proposal (proposal and oral defense), Ph.D. thesis and successful defense

- Ph.D. proposal: Every student needs to develop a written Ph.D. proposal incl. research plan in cooperation with his Ph.D. Advisor. It has to be presented in public upon invitation by the Dean at most eight months after the qualifying exam or after entrance into the Ph.D. Program. The presentation of about 30 minutes should be followed by an oral defense of 30-60 minutes. The Dissertation Committee approves the Ph.D. Proposal. In exceptional cases, students might combine the Ph.D. proposal with an M.Sc. thesis in one document. This needs to be discussed in detail with and approved by the Graduate Advisor as well as the Program Coordinator.
- Ph.D. defense: After approval of the Ph.D. thesis, the candidate need to present his research in a presentation of 30-40 minutes followed by an oral defense of 45-90 minutes. The Dissertation Committee approves the Defense.
- Publication of Ph.D. thesis

Any adjustments/amendments need to be discussed with the Program Coordinator. For further details please also see the Graduate Policies of the Jacobs University and the accompanying guidelines.

3.2.4 Graduation Requirements for Ph.D. only

- The requirements for a Ph.D. include the admission to the Ph.D. phase, an approved Ph.D. proposal, an approved Ph.D. thesis, successful defense as well as publication of the PhD thesis. The details are the same as described above. Please also see the Graduate Policies of Jacobs University and the accompanying guidelines.

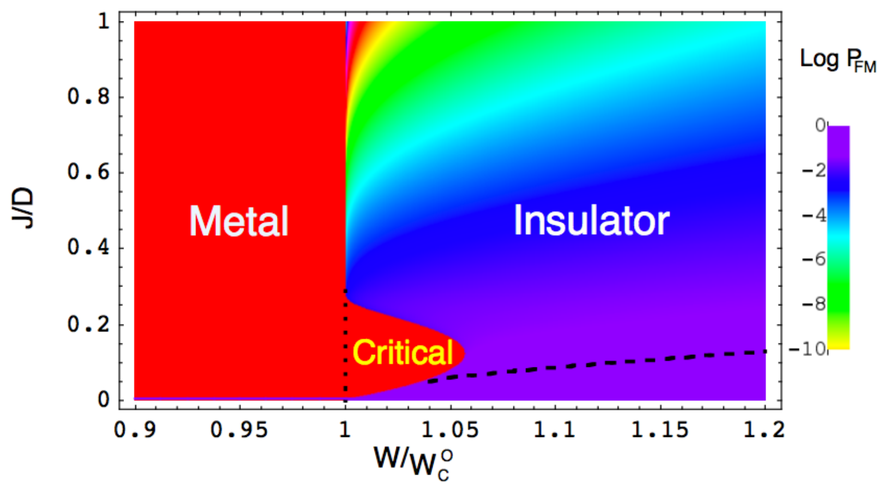


Fig.:The Quantum Phase Diagram, here shown as function of Disorder W and Exchange Coupling J, reveals rich physics: A new quantum phase of matter, the critical metal, arises due to the interplay of Disorder and Spin Correlations.

3.3 Recommended Course Plan: Physics Track

Semester 1 Courses	**Course Number**	**C**	**T**
Advanced Quantum Mechanics	420531	5	m
Physical Sciences Research Methods	420421	10	m
Current Topics in Physical Sciences	420472	5	e
Elective Course (see final section for a list of courses)		5	e
Elective Course		5	e
Semester 2 Courses	**Course Number**	**C**	**T**
Advanced Statistical Physics	420482	5	m
From Molecules to Matter	420441	5	m
Physical Sciences Graduate Student Seminar I	420412	5	m
Physical Sciences Advanced Guided Research I	420462	10	m
Elective Course		5	e
Semester 3 Courses	**Course Number**	**C**	**T**
Classical and Quantum Field Theory **(every 2nd year only)**	420401	5	m
Physical Sciences Graduate Student Seminar II	420511	5	m
Physical Sciences Advanced Guided Research II	420461	10	m
Elective Course		5	e
Elective Course		5	e
Semester 4 Courses (M.Sc. only)	**Course Number**	**C**	**T**
Physical Sciences Independent Research and M.Sc. thesis	420522	30	m

C = ECTS credit points, T=type (m=mandatory, e=elective)

Notes:

1. Though all four courses ”Advanced Quantum Mechanics”, ”Advanced Statistical Physics”, ”From Molecules to Matter”, and ”Classical Field Theory” are highly recommended, only 15 ECTS from these courses are mandatory for graduation.
2. Research Methods, Advanced Guided Research and M.Sc. Thesis comprises work in one or more experimental research labs or theory groups at Jacobs University on topics of current interest. A written M.Sc. thesis (40 pages suggested) and an oral presentation of the results are required. Students should contact faculty regarding a research topic.

Recommendation Professional Skills

The SES highly recommends attending the Professional Skills seminars offered by the Career Services Center. Those seminars include soft skills development seminars and application trainings which will help you cope with your studies and master internship and job search.

Further details can be found at the Teamwork server of the university at
https://teamwork.jacobs-university.de/confluence/display/APS

Nanoscience Track

with

Ph.D. in Chemistry or Physics

and

M.Sc. in Nanomolecular Science

4 Nanoscience Track

4.1 Concept

4.1.1 Nanoscience

The physical sciences have reached a state that enables us, at least in principle, to build objects at the ultimate level of finesse, one atom or molecule at a time, with ultimate precision. At the nanometer length scale, the traditional scienof physics, chemistry and biology loose their distinctiveness and merge into a new transdisciplinary science, commonly known as ”Nanoscience” and its concomitant technology. In this new scientific endeavour, each of the traditional sciences has an invaluable contribution to make. Given the scope of Nanoscience and Nanotechnology, it is not surprising that they hold answers to our most pressing material and technological needs. For example, advanced organic solar cells based on new functional materials, fuel cells incorporating nano-catalysts and novel hydrogen storage systems based on molecularly engineered materials could help usher in sustainable energy solutions. Wires, transistors, and storage media of the size of single molecules will introduce a paradigm shift in information technology. The construction of molecular shuttles, rotors and wheels realizes mechanical tools at the nanoscopic level, while the design of molecular barrels, cups, chains and knots transfers macroscopic objects to the nanoscale. Molecular medicine is looking for ultrasmall and less invasive detection techniques in diagnostics and delivering systems employing nanocontainers to advance progress and treatment of diseases. These are just a few examples of how (molecular) nanotechnology can transform our future.

4.1.2 Scope of the Nanoscience Track

The Nanoscience track is, by its nature, highly transdisciplinary. Physics has developed novel observation and manipulation tools for single atoms and molecules and provides quantum physics as the fundamental science of the small. *Chemistry*, the science of molecules, now allows molecules to be designed with higher order functions from seemingly simple building blocks, e.g. supramolecular assemblies can be tailor made through an in depth knowledge of attractive forces (ionic, covalent, and non-covalent), conformation, and reactivity. Research in *biology* is currently revealing the toolbox of real-life molecular machinery and teaches us how nanosized objects can be self-assembled into complex systems in which dynamic nanomolecular functions like signalling, catalysis, transport, and locomotion can be realized in a controlled way. Finally, *materials science* converts the nanoscale properties of components into macroscopic materials with entirely novel properties and functionalities.

The Nanoscience track in the Physical Sciences Graduate Program at Jacobs University reflects the need for transdisciplinary training. Faculty from the physical, chemical and biological sciences provide lectures and lab classes in the nano-related aspects of their fields. The education covers different classes of nanomaterials, different synthesis and characterization methods, various theoretical and computational approaches as well as application areas of nanomaterials. The course work provides an interdisciplinary breadth to the granted degree. The M.Sc. or Ph.D. thesis allows for the in-depth study of a particular topical research area in the lab of the participating faculty. Thus participants emerge from the program track with a versatile background in Chemistry, Physics and Nanoscience, as well as with the ability to perform independent research in a results-oriented approach.

4.1.3 Target Group

The program is aimed at students with an excellent record in undergraduate chemistry, physics or closely related subjects (material science, physical chemistry, ...). A very good working knowledge of English is mandatory. A minimum of four course in the area of chemistry and/or physics is highly desirable.

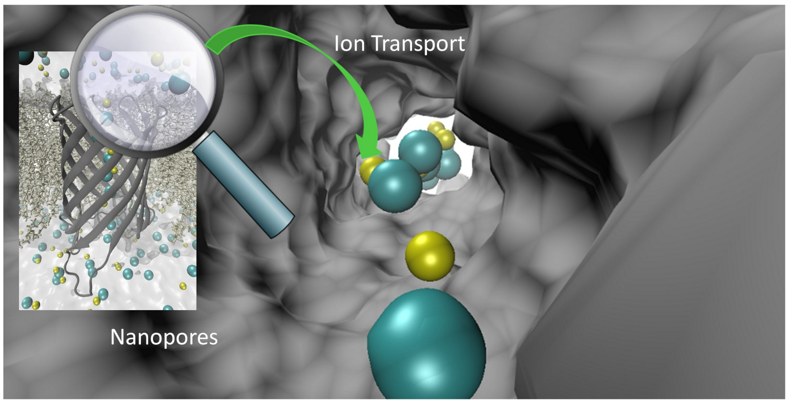


Fig.: Ion and substrate transport through nanopores by theory and experiment.

4.2 Graduation Requirements for the Nanoscience Track

4.2.1 Course Work Requirements

90 ECTS from lectures, practical training and seminars

4.2.2 Graduation Requirements for M.Sc. in Nanomolecular Science

Successful completion of course work, practical training, and seminars plus 30 ECTS for independent research and approved Master thesis. The course work consists of

- mandatory lectures: Supramolecular Chemistry, Nanomolecular Science, From Molecules to Matter, and one of the two courses: Introduction to Computational Chemistry including laboratory **or** Advanced Quantum Mechanics (20 ECTS)
- mandatory practical training: Physical Sciences Research Methods, Physical Sciences Advanced Guided Research I & II (30 ECTS)
- mandatory seminars: Current Topics in Physical Sciences, Physical Sciences Graduate Seminar I & II (15 ECTS)
- elective courses: see final chapter for a list of courses (25 ECTS)

Each course can only be counted once towards one of the M.Sc. or Ph.D. degrees offered in the program.

During the first three semester, 90 ECTS credit points for course work need to be accumulated. Out of this 90 ECTS points, 60 ECTS points are for lectures as well as seminars and 30 ECTS points for practical training and research. In case of an M.Sc. study, additional 30 ECTS points for Independent Research and the M.Sc. thesis in the fourth semester are mandatory.
Up to 20 ECTS credit points of the electives can be substituted by suitable graduate courses from other graduate programs at Jacobs University, certain 3rd year undergraduate specialization courses or courses in the framework of joint graduate schools with external universities. The latter courses might be offered as block courses in some cases. Substitutions are subject to approval by the Graduate Advisor and Program Coordinator. 3rd-year courses may only be credited if they have not been credited towards their undergraduate degree. Students can take additional courses (lectures, labs, seminars; within or outside the Physical Sciences graduate program; graduate or undergraduate level) in order to broaden or deepen their field of study.

4.2.3 Graduation Requirements for Integrated Ph.D.

- Promotion to Ph.D. phase: Successful completion of course work plus qualifying exam.
- Qualifying Examination: Oral (or written) exam on Nanomolecular Science, Introduction to Computational Chemistry including laboratory **or** Advanced Quantum Mechanics, Supramolecular Chemistry, and one elective. The selection has to be discussed with the Academic Advisor and communicated to the Program Coordinator. In agreement with the Graduate policies, the Qualifying Examinations in Integrated Ph.D. Programs take place before the beginning of the fourth semester, assuming that the student has completed the coursework requirements. In case of an oral exam, at least three faculty members must be present, and the typical duration is no less than one hour. The Qualifying Examination has the outcome “pass” or “fail”.
- Requirements for Ph.D.: Admission to Ph.D. phase, approved Ph.D. proposal (proposal and oral defense), Ph.D. thesis and successful defense

- Ph.D. proposal: Every student needs to develop a written Ph.D. proposal incl. research plan in cooperation with his Ph.D. Advisor. It has to be presented in public upon invitation by the Dean at most eight months after the qualifying exam or after entrance into the Ph.D. Program. The presentation of about 30 minutes should be followed by an oral defense of 30-60 minutes. The Dissertation Committee approves the Ph.D. Proposal. In exceptional cases, students might combine the Ph.D. proposal with an M.Sc. thesis in one document. This needs to be discussed in detail with and approved by the Graduate Advisor as well as the Program Coordinator.
- Ph.D. defense: After approval of the Ph.D. thesis, the candidate need to present his research in a presentation of 30-40 minutes followed by an oral defense of 45-90 minutes. The Dissertation Committee approves the Defense.
- Publication of Ph.D. thesis

Any adjustments/amendments need to be discussed with the Program Coordinator. For further details please also see the Graduate Policies of the Jacobs University and the accompanying guidelines.

4.2.4 Graduation Requirements for Ph.D. only

- The requirements for a Ph.D. include the admission to the Ph.D. phase, an approved Ph.D. proposal, an approved Ph.D. thesis, successful defense as well as publication of the PhD thesis. The details are the same as described above. Please also see the Graduate Policies of Jacobs University and the accompanying guidelines.

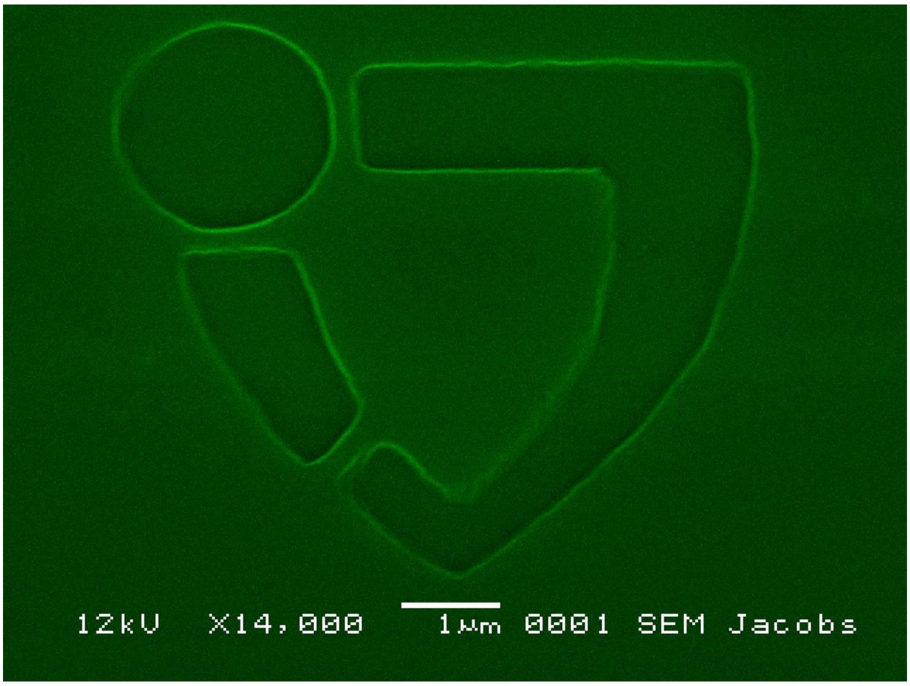


Fig.: Jacobs University logo on the micrometer scale.

4.3 Recommended Course Plan: Nanoscience Track

Semester 1 Courses	Course Number	C	T
Introduction to Computational Chemistry		2.5	m
Introduction to Computational Chemistry - Laboratory		2.5	m
or Advanced Quantum Mechanics	420531		
Physical Sciences Research Methods	420421	10	m
Current Topics in Physical Sciences	420472	5	e
Elective Course (see final section for a list of courses)		5	e
Elective Course		5	e

Semester 2 Courses	Course Number	C	T
Supramolecular Chemistry	420432	5	m
Nanomolecular Science	420431	5	m
From Molecules to Matter	420441	5	m
Physical Sciences Graduate Student Seminar I	420412	5	m
Physical Sciences Advanced Guided Research I	420462	10	m

Semester 3 Courses	Course Number	C	T
Physical Sciences Graduate Student Seminar II	420511	5	m
Physical Sciences Advanced Guided Research II	420461	10	m
Elective Course		5	e
Elective Course		5	e
Elective Course		5	e

Semester 4 Courses (M.Sc. only)	Course Number	C	T
Physical Sciences Independent Research and M.Sc. thesis	420522	30	m

C = ECTS credit points, T=type (m=mandatory, e=elective)

Note:

1. Research Methods, Advanced Guided Research and M.Sc. Thesis comprises work in one or more experimental research labs or theory groups at Jacobs University on topics of current interest. **Research experience has to be gained in research groups from different research disciplines.** A written M.Sc. thesis (40 pages suggested) and an oral presentation of the results are required. Students should contact faculty regarding a research topic.

Recommendation Professional Skills

The SES highly recommends attending the Professional Skills seminars offered by the Career Services Center. Those seminars include soft skills development seminars and application trainings which will help you cope with your studies and master internship and job search.

Further details can be found at the Teamwork server of the university at
https://teamwork.jacobs-university.de/confluence/display/APS

Course Offerings

5 Course Offerings

> Jacobs University Bremen reserves the right to substitute courses by replacements and/or reduce the number of mandatory/mandatory elective courses offered

5.1 Regular Courses

420441 – From Molecules to Matter

Short Name: MoltoMat
Instructors: Veit Wagner, Ulrich Kleinekathöfer
Credit Points: 5 ECTS, mandatory in Physics and Nanoscience
Semester: Fall

Course content The first part of the course provides foundations as basis knowledge necessary for understanding and describing nano-scale systems covering fundamental physical aspects. It covers the statistical approach to thermodynamics of multi-particle system. Quantum statistics of electrons, vibrations and photons are introduced to calculate various thermodynamic properties. Furthermore electromagnetic fields and there modification in matter and in cavities is addressed. Throughout the first part special emphasis is given to the scaling behaviour from infinite systems to systems of finite size. The second part provides a survey of the field nano-scale systems and will start off with an introduction to imaging, characterisation and manipulation techniques of nanoobjects and single molecules. This includes scanning probe microscopies (e.g. STM, AFM, SNOM) and other single molecule detections and analysis techniques (patch clamp, optical tweezers, fluorescence spectroscopy and microscopy). Also, fundamental properties of nanoscale materials (confinement, size dependent properties) will be discussed. The module is rounded of by a short account of methods to create nanostructures at surfaces.

Textbooks

- Introductory Nanoscience: Physical and Chemical Concepts, M. Kuno (Garland, 2011)
- Solid State Physics, N.W. Ashcroft, N.D. Mermin (Rinehart&Winston, 1976);
- Scanning Probe Microscopy: Analytical Techniques, Ed. R. Wiesendanger
- Nanoelectronics and Information Technology, Ed. R. Waser

420431 – Nanomolecular Science

Short Name: Nanomol
Instructors: Werner Nau, Ulrich Kortz, Jürgen Fritz
Credit Points: 5 ECTS, core course in Chemistry and Nanoscience
Semester: Fall

Course content This courses on Nanoscience which provide a survey of the field, both from a chemical and physical point of view. After a general introduction to the field, the course will focus on the (chemical) synthesis of various nanoparticles, including fullerenes and carbon nanotubes as well as metallic, semiconducting and ceramic nanoparticles. Aspects of their structure, properties and selected applications (catalysis) will also be covered. Finally, nanoporous materials (zeolites) and nanocrystalline materials will be treated. The second module will start off with an introduction to imaging, characterisation and manipulation techniques of nanoobjects and single molecules. This includes scanning probe microscopies (e.g. STM, AFM, SNOM) and other single molecule detections and analysis techniques (patch clamp, optical tweezers, fluorescence spectroscopy and microscopy). Also, fundamental properties of nanoscale materials (confinement, size dependent properties) will be discussed. The course is rounded of by a short account of methods to create nanostructures at surfaces.

420432 – Supramolecular Chemistry

Short Name: SupraChem
Instructors: Nikolai Kuhnert, Detlef Gabel, Werner Nau
Credit Points: 5 ECTS, core course in Chemistry and Nanoscience
Semester: Spring

Course content The course will introduce the principal design of nanomolecular systems, their characteristic properties, principal functions and applications. The focus will lie on organic and biological functional systems and on applications in the physical sciences, thus complementing the inorganic, materials-related and methodological aspects covered in Nanomolecular Science. It deals with supramolecular chemistry, the construction of nanomolecular functional systems including shuttles, photonic devices, molecular rotors and machines, and molecular containers, including biological examples and applications, e.g., drug delivery and high-throughput screening. Synthetic aspects of supramolecular assemblies, both of discrete monodisperse nature (calixarenes, functionalized fullerenes, cyclodextrins, cucurbiturils), as well as less well defined polydisperse systems like dendrimers will be discussed.

xxx – Introduction to Computational Chemistry

Short Name: IntroCompChem
Instructors: Thomas Heine, Agnieszka Kuc
Credit Points: 2.5 ECTS, core course in Chemistry and Nanoscience
Semester: Fall

Course content Lecture with strong interactive component, closely connected to the lecture. Last 3 weeks of semester student presentations on computational chemistry project chosen by student and instructors with relation to research interest of the student.

1. Introduction (Aim of the course, history, open discussion with participants)
2. Basis Sets
3. Geometry Optimization
4. Density Functional Theory
5. Ionization Potential / Electron Affinity
6. Vibrational Spectroscopy I
7. Vibrational Spectroscopy II (includes symmetry)
8. Thermochemistry
9. NMR
10. Transition State Theory

11. TD-DFT
12. Treating Solvents using Reaction Fields
13. Understanding the Chemical Bond via Topological Analysis

xxx – Introduction to Computational Chemistry - Laboratory

Short Name: IntroCompChemLab
Instructors: Agnieszka Kuc, Thomas Heine
Credit Points: 2.5 ECTS, core laboratory in Chemistry and Nanoscience
Semester: Fall

Course content Hands-On sessions, starting with Quiz (15 min, testing prerequisite knowledge as provided in the instructions). Lab report is required.

1. Introduction (Lab: to Software (Linux, Gaussview, Molden, etc.))
2. Basis Sets
3. Geometry Optimization
4. Density Functional Theory (Lab: Functionals: LDA, GGA, meta-GGA, etc.)
5. Ionization Potential / Electron Affinity
6. Vibrational Spectroscopy I
7. Vibrational Spectroscopy II (includes symmetry)
8. Thermochemistry
9. NMR
10. Transition State Theory
11. TD-DFT
12. Treating Solvents using Reaction Fields
13. Understanding the Chemical Bond via Topological Analysis

420542 – Experimental Techniques

Short Name: ExpTech
Instructors: Jrgen Fritz
Credit Points: 5 ECTS, core course in Chemistry
Semester: Fall

Course content This course introduces to the major experimental and analytical techniques to analyze the structure and activity of molecules. It discusses basic methods commonly used by physicists, chemists, and life scientists to characterize molecular systems of interest. It starts with a general introduction to basic interactions between atoms and molecules and their environment, needed to understand the working principles of experimental techniques. The main part focuses on the individual experimental technique including X-ray diffraction, NMR, mass spectrometry, optical spectroscopy, microscopy, light scattering, calorimetry and electrochemistry.
Some basic concepts from physics and physical chemistry and a certain basic mathematical background are necessary to understand the working principle of the different instruments. Using an interdisciplinary approach, we will discuss the theoretical background and applications

of the different methods, complemented by visits of Jacobs research labs using those analytical instruments.
The course serves as an introductory course to analytical techniques for MSc students. It can also serve as a specialization for 3rd year undergraduate students in physics, chemistry, or other majors interested in an overview of modern experimental techniques in physical chemistry, biophysics, analytical chemistry, or material science.

420531 – Advanced Quantum Mechanics

Short Name: AdvQM
Instructors: Stefan Kettemann
Credit Points: 5 ECTS, core course in Physics
Semester: Fall

Course content This course gives an introduction into advanced concepts of quantum mechanics. Starting with the nonrelativistic formulation of quantum mechanics in the presence of electromagnetic fields, we derive the Stark effect, the Landau quantisation and the Aharonov-Bohm Effect. Reviewing quantum interference phenomena, we motivate and derive the Feynman' path integral formulation of QM. Scattering theory is introduced. After a review of the concept of spin, we study spin dynamics, geometric phase, spin-orbit interaction, and its derivation from the Dirac Equation, and the Klein-Gordon equation for Fermions and Bosons, respectively. We introduce the concept of entanglement and review quantitative entanglement measures. After an introduction to Green's functions, and correlation functions, we derive the linear response approximation to the susceptibility and conductivity. We conclude with a review of the quantum theory of many body systems.

420482 – Advanced Statistical Mechanics

Short Name: AdvStatPhys
Instructors: Hildegard Meyer-Ortmanns, Ulrich Kleinekathöfer
Credit Points: 5 ECTS, core course in Physics
Semester: Fall

Course content The course starts with a summary on ideal quantum gases of bosons and fermions. It covers topics like Bose-Einstein condensation, real gases, the virial expansion, spin systems and magnetism, phase transitions and critical phenomena. A number of analytical and numerical methods will be reviewed. While the first part deals with systems in equilibrium, the last part gives an introduction to systems out-of-equilibrium that are currently at the frontiers of research in view of application. Topics here are the Boltzmann equation, kinetic gas theory and a variety of stochastic processes.
Prerequisite for this course is an undergraduate course on the basics of thermodynamics and statistical physics.

420401 – Classical and Quantum Field Theory

Short Name: FieldTheor
Instructors: Peter Schupp
Credit Points: 5 ECTS, core course in Physics
Semester: Fall, every 2nd year

Course content All fundamental forces of nature are described in terms of fields (at least at currently experimentally accessible energy scales). Classical and quantum field theory provides the foundation for much of physics. A thorough knowledge of the theory is indispensable for particle physics and gravitational physics and very helpful for condensed matter/solid state physics and many other fields. The course includes a review of relevant background material in physics and mathematics.
Topics: Special relativity, point particles and extended objects in background fields, continuum limit and fields; the scalar field, symmetries and conservation laws; gauge symmetry and gauge fields, Maxwell's equations and their solutions, boundary value problems, electromagnetic radiation, electromagnetic fields in media (optics); non-abelian gauge theory, spontaneous symmetry breaking with applications in particle physics and condensed matter theory; general relativity, Einstein's equations and important solutions; applications to the physics of stars, black holes, and cosmology; quantum field theory, canonical quantization, path integrals, Feynman diagrams, renormalization; selection of more advanced topics.

420452 – Structural Methods in Nanoscale Science

Short Name: StrucMethNanoScaleSci
Instructors: Ulrich Kortz
Credit Points: 5 ECTS, elective
Semester:

Course content This course deals with modern analytical instrumentation used for the structural characterization of inorganic compounds, e.g. nuclear magnetic resonance spectroscopy, electron spin resonance spectroscopy, NQR, mass spectrometry, Mössbauer spectroscopy, and diffraction techniques. The course is designed to teach students interpret experimental data, understand the material published in modern research journals, and make decisions about what techniques will be the most useful in solving particular structural problems. The course makes a strong connection between theoretical topics and the real world of practicing chemists.

Textbooks

- Structural Methods in Inorganic Chemistry, Eds. Ebsworth, Rankin, Cradock (CRC Press)

200472 – General Relativity

Short Name: GenRel
Instructors: B. Hartmann
Credit Points: elective, 5.0 ECTS
Semester: Spring

Course content General Relativity describes Gravitation in terms of the curvature of space-time. While in Special Relativity, space-time is rigid, it becomes dynamical in General Relativity and interacts with matter/energy. The interaction between matter and space-time is governed by the famous Einstein equations. The first part of the course is concerned with the mathematical and geometrical aspects of General Relativity, while the second part will contain consequences of the theory such as black holes and cosmological models.

200432 – Advanced Solid State Physics

Short Name: ASSP
Instructors: S. Kettemann
Credit Points: elective, 5.0 ECTS
Semester: Spring

Course content This course offers an overview and guideline to understand modern problems of solid state physics including Superconductivity, Bose-Einstein condensation, Ferromagnetism, Spintronics, (Fractional) Quantum Hall Effects, Kondo Effect, Strongly Correlated Systems, and Quantum Phase Transitions, and Topological Insulators.

2004xx – Phase Transitions and Critical Phenomena

Short Name: PhaseTrans
Instructors: Hildegard Meyer-Ortmanns
Credit Points: elective, 5 ECTS
Semester: Fall

Course content Phase transitions are ubiquitous phenomena in nature. They are found in systems ranging from the early universe, particle physics, condensed matter physics, neural networks, biological systems, and computer science. For example, they go along with a change of the systems' symmetries, their particle contents, their state of magnetization, their memory capacity, their patterns of synchronization, or with a change of the convergence speed of algorithms for solving optimization problems in computer science. Often these changes are quite abrupt, and only a detailed analysis reveals their characteristic precursors, in particular if we have to deal with critical phenomena. We shall provide examples from different branches of physics and beyond. After presenting a classification scheme of phase transitions and their phenomenological characterization, we consider the Ginzburg-Landau theory as one of the basic analytical tools for their prediction and analysis, followed by a primer to the renormalization group which leads to a theoretic understanding of critical phenomena. Under certain conditions critical phenomena may be even self-organized, so that no fine-tuning of parameters is needed. We shall give an outlook to this phenomenon, called self-organized criticality.
Prerequisite for this course is an undergraduate course on the basics of thermodynamics and statistical physics.

420501 – Theory for Spectroscopy Simulations

Short Name: Theoretical Spectros
Instructors: Thomas Heine
Credit Points: elective, 5 ECTS
Semester: Fall

Course content This course the theory for simulations of spectroscopy data will be given. The course will cover molecular (infrared, Raman, UV/Vis, NMR, ERP) and solid state (EELS, XANES, XAS, XES, PES) spectroscopy as well as XRD. Homeworks will cover computer experiments and individual reading assignments.

420471 – Transport Physics and Electronic Devices

Short Name: TransPhysElecDev
Instructors: Veit Wagner
Credit Points: elective, 5 ECTS
Semester: Spring

Course content The course introduces to the phenomena of transport processes in condensed matter and the physical concepts to describe them. This includes the discussion of heat, sound and electronic transport. With emphasis on the latter, electronic devices serve as model systems to understand the transport in macroscopic structures as well as in nano-scale devices. Required modifications of macroscopic transport models to describe transport in nano and single molecule structures are introduced and discussed. In parallel to theoretical concepts the basic experimental techniques applied to analyze transport properties are introduced.

xxx – Molecular Physics

Short Name: MolPhys
Instructors: Arnulf Materny
Credit Points: elective, 5 ECTS
Semester: Fall

Course content Molecular Physics is on the one hand closing the gap between Atomic Physics and Solid State Physics and on the other hand creates an important link to Chemistry. The course will start with at brief repetition of atomic physics concepts (quantum numbers, He atom, orbital approximation, exchange). The molecular Hamiltonian and the Born-Oppenheimer approximation will be then be used to describe electronic structure as well as ionic and covalent bonding. Vibrational structure and wavefunctions will be introduced and rotational energy levels will be discussed. Ionisation and dissociation will be pointed out as important molecular energy scales. Techniques for the experimental characterization of molecules will be also an important part of the lecture with special emphasis on optical spectroscopy. Keywords here are e.g. ”selection rules”, ”Franck-Condon principle”, ”Raman scattering”, and ”absorption spectra”.

Basic knowledge of the undergraduate Quantum Physics courses will be required. Atomic Physics basics will be partially repeated, but previous experience from an introductory course would be advantageous.

530462 – Computational Challenges in Biology and Biophysics

Short Name: CompBiol
Instructors: Marc-Thorsten Hütt; Ulrich Kleinekathöfer
Credit Points: elective, 5 ECTS
Semester: Spring

Course content Computational approaches to analyzing, understanding and predicting biological processes have developed rapidly in the last decade and have by now an important role in virtually every fields of biological research. With these lectures we aim at highlighting the current computational achievements in different areas of biology, their limits and possible future developments. Topics include: predicting protein structure from sequences, understanding genome evolution, simulating cells, Molecular and Brownina dynamics, simulating membrane transport with atomic resolution, predicting epidemic spreading of diseases and analyzing patterns of brain activity.

530421 – Biological Thermodynamics, Kinetics, and Separation

Short Name: BioThermKinSep
Instructors: Jürgen Fritz; Mathias Winterhalter
Credit Points: elective, 5 ECTS
Semester: Spring

Course content This course focuses on the thermodynamics and kinetics of structure formation and association of biomolecules, a theme of central importance for biological recognition. It includes a discussion of theoretical methods to describe thermodynamic driving forces for association and structure formation and how to analyze cooperative effects. The course is also intended to give a comprehensive overview on experimental methods to measure thermodynamic contributions and how to investigate the kinetics of biological processes at various time scales. In addition, separation methods that are based on differences in the physical properties of proteins and other biomolecules will be discussed in detail. The course focuses on the experimental methods and theoretical background to understand the biophysics of cellular membranes. The framework is an introduction to systems, experimental and theoretical methods in biophysics. The course should address biophysics interested M.Sc. students.

200352 – Principles and Applications of Optical Spectroscopy

Short Name: Spectroscopy
Instructors: Arnulf Materny
Credit Points: elective, 5 ECTS
Semester:

Course content Optical spectroscopy is a powerful technique for investigating electronic and vibrational properties of a variety of systems. In nanostructured systems, the techniques of absorption, reflection, luminescence, and light-scattering spectroscopies are capable of providing invaluable information about diverse aspects. This course gives an introduction to the different spectroscopic techniques which are used in the field of laser spectroscopy. The prerequisites will be the lectures on quantum mechanics of atoms, molecules, and solids. In the beginning, the instrumentation of laser spectroscopy will be introduced. Especially the different types of lasers will be explained. Then techniques making use of the spectral information will be discussed, starting with absorption and luminescence spectroscopy. Other examples are Raman spectroscopy and finally also nonlinear spectroscopic methods. The course will after this introduce the methodology of femtosecond time-resolved spectroscopy, which gives access to the dynamics of both internal molecular processes and chemical reactions. At the end of the course, possible applications of the spectroscopic techniques (e.g. in combination with SNOM) for the investigation of nanostructures will be discussed.

Textbooks

- Wolfgang Demtröder, Laser Spectroscopy (Springer, NY, 2002), 3rd ed.

420492 – Nanoanalytics

Short Name:	NanoAna
Instructors:	Veit Wagner
Credit Points:	5 ECTS, elective
Semester:	

Course content This Graduate level course is designed for physicist and students of neighboring disciplines, i.e. chemists and electrical engineers, with basic knowledge in solid state physics. It introduces in systematic order experimental methods for condensed matter analysis with special emphasis on methods with relevance to nanoscience. Where necessary special sample preparation methods are discussed together with the measurement principle and the measurement quantities and measurement accuracy. Methods discussed include basic methods, like x-ray diffraction, photo electron spectroscopy and scanning electron microscopy, up to advanced complex machinery as e.g. high resolution techniques available at synchrotron radiation facilities.

420502 – Density-Functional Theory

Short Name:	DFT
Instructors:	Thomas Heine
Credit Points:	elective, 5 ECTS
Semester:	Spring

Course content The course addresses graduate students (Ph.D. and Master) specializing in Theoretical Physics and Chemistry and those who want to use Computational Physics and/or Chemistry with solid background in these projects. All participants need to have a login on the university supercomputer facility (access can be provided beforehand), The aim of the course is to teach both the theoretical foundations of DFT as well as the tricks of the trade. The course will cover:

1. Hohenberg-Kohn Theorems
2. Electron correlation functionals
3. Exchange-correlation functionals
4. DFT in local basis set representation
5. Pseudopotentials / Effective Core Potentials
6. DFT in plane wave representation
7. FR-LAPW and PAW
8. Relativistic effects
9. Limitations of DFT
10. London dispersion correction
11. Time-Dependent DFT
12. Quantized-Liquid DFT

There is no standard text, chapters are taken mainly from the original literature, but also from the Parr-Young, Dreizler-Gross and Cramer texts.
Tutorials and homeworks will be combined to a logical unit. The students will learn to use some example codes (ADF/BAND, TurboMole, VASP, WIEN2k). Phd Students will be actively involved in the tutorials.

420551 – Computational Solid State and Surface Physics

Short Name: CSSSP
Instructors: Thomas Heine
Credit Points: 5 ECTS, elective
Semester: Fall

Course content In the lectures, the topics will be introduced from the experimental and from the theoretical viewpoints. The aim is to show what exactly is simulated (with all models and approximations clearly discussed), and what is measured (with explanations about accuracy and secondary effects). Students will be in charge of the Hands-On sessions. They will present a short review of the problem to the class, and explain it on a concrete example. Then, in a Hands-On session, the computational task - that is, how exactly the simulation is carried out - will be explained. The information will be presented in front of the class, and the tutorial shall be prepared in a document that will be distributed in class. Finally, the homeworks will be presented. Students will work closely with an instructor in order to prepare Hands-On session, tutorial and homeworks. Homeworks can be solved individually or in groups. They will be graded by the student and instructor responsible for the respective Hands-On session.

200391 – Physics of the Early Universe

Short Name: PhysEarlyUniverse
Instructors: B. Hartmann
Credit Points: 5 ECTS, elective
Semester:

Course content While particle physics deals with physics on the smallest scales, cosmology is mainly concerned with physics on the largest scales. To understand the structure we see in the universe today, it is vital to have knowledge about the early universe. Due to the extreme conditions in the early universe, especially the high energies, which (up to now) cannot be simulated in terrestrial accelerators, it is a very good testing ground for theories beyond the standard model such as Grand Unified Theories (GUTs) or even String Theory. In this sense, the early universe is the main ground to understand the interplay between cosmology and astrophysics on the one hand and particle physics on the other hand. In this lecture, we will start with a brief overview of what is known about the universe today. Topics include the cosmic microwave background, the large-scale structure of the universe as well as the abundance of different elements. In what follows, we will illustrate how these observations can be explained in the so-called ”Hot Big Bang” model of the universe. Topics here are nucleosynthesis, baryogenesis as well as phase transitions and the inflationary epoch.

200421 – Strings, Branes, and Matrices

Short Name:	StringBranMat
Instructors:	P. Schupp
Credit Points:	5 ECTS, elective
Semester:	

Course content A contemporary introduction to selected topics of high-energy physics with focus on string theory; brief review of relevant topics from quantum field theory (path integrals, supersymmetry); closed and open strings and their quantization, background fields, D-branes, effective actions; M(atrix) theory; non-commutative geometry and string theory; choice of advanced topics.

210322 – Gravity in Geophysics and Planetary Sciences

Short Name:	GravityGeoPlanet
Instructors:	J. Vogt
Credit Points:	2.5 ECTS, elective
Semester:	Spring

Course content Gravity anomalies on planetary surfaces result from density inhomogeneities in the interior and can thus provide information about the composition and structure of the subsurface. On large spatial scales, gravity meters and accelerometers on orbiting spacecraft are the most efficient means to map gravity anomalies. In geophysical exploration, gravity methods are used to study anomalies on small and regional spatial scales. This course provides a general introduction to gravity methods in both geophysics and planetary sciences. We utilize potential theory and spherical harmonics for large scales. Gravity data processing and interpretation are discussed in the light of geophysical inverse methodology.

210332 – Magnetism in Geophysics and Planetary Sciences

Short Name: MagnetismGeoPlanet
Instructors: J. Vogt
Credit Points: 2.5 ECTS, elective
Semester: Spring

Course content On Earth and other planets, magnetic phenomena are found on a wide spectrum of spatial scales ranging from small-scale magnetic anomalies caused by magnetized surface rocks to global magnetic fields generated through dynamo action in planetary interiors. This course provides a general introduction to magnetic fields and magnetic methods in both geophysics and planetary sciences. Topics include magnetic instruments, measurements, data processing, interpretation and modeling.

200232 – Reductionism in Physics and its Relation to Philosophy

Short Name:
Instructors: Hildegard Meyer-Ortmanns
Credit Points: 5 ECTS, elective
Semester:

Course content The aim of the course is to discuss both the success and the limitations of methodological reductionism in physics. The first part shall illustrate reductionism's success in different areas of physics: relativity theory, gauge theories of the standard model, self-organized processes like pattern formation in cosmology, the renormalization group approach in condensed matter theory, and more generally in topics of multi-scale modeling. Guiding principles and tools shall be analyzed that make this success possible. The second part deals with limitations of reductionism which show up when the goal is to predict not only a single aspect, but the whole variety of emergent phenomena on a higher level, starting from a known underlying level of description. Furthermore, the very formulation of physical laws in stochastic and deterministic versions shall be reviewed, and along with them, an important topic in the theory of evolution that is related to the role of contingency and necessity in systems' time evolutions, in particular in the evolution of the universe. From illustrations of the successful application of reductionism in different branches of physics, undergraduate students are expected to receive first reviews on great achievements in physics rather than obtaining a detailed understanding. A deeper understanding can be gained upon specialization on the graduate level. On the other hand, pointing out the limitations of reductionism opens the view for the need to include other disciplines than physics to approach complex systems in all its facets.

210392 – Geophysical Time Series Analysis

Short Name: GeoTimeSeries
Instructors: J. Vogt
Credit Points: Lecture, 5.0 ECTS, elective
Semester: Spring

Course content In geosciences and space physics, data often come in the form of time series. This course covers important approaches to time series analysis such the statistical description of data, correlation and regression, auto-correlation and cross-correlation functions, Fourier analysis, spectrum estimation, filtering, and modeling of data. Short reviews of the underlying theory are embedded in hands-on computer lab sessions where the students familiarize with the practice of time series analysis and interpretation. They learn to assess the potential and the limitations of the analysis methods, and apply them to measurements.

200xxx – Condensed Matter Field Theory

Short Name: CondMatField
Instructors: S. Kettemann
Credit Points: Lecture, 5.0 ECTS, elective
Semester: Fall

Course content Over the past few decades, in concert with ground-breaking experimental advances, condensed matter theory has drawn increasingly from the methods of low-energy quantum field theory. This course is aimed at elevating graduate students of condensed matter theory to a level where they can engage in independent research. It emphasizes the development of modern methods of classical and quantum field theory with applications oriented around condensed matter physics. Methods covered include second quantization, path and functional field integration, mean-field theory, Ginzburg-Landau Theory of critical phenomena, the renormalization group method, and topological field theories. These Methods are applied to phenomena of modern physics like superconductivity, Bose- Einstein condensation,magnetism, quantum Hall effect, Kondo effect and Quantum Phase Transitions. The discussion will be rooted firmly in practical experimental application. As well as routine exercises, the course will guide through extended and challenging problems, designed to provide a bridge between formal manipulations and research- oriented intuitive thinking.
Prerequisites: Solid State Physics, Quantum Mechanics I and II, Statistical Physics

560351 – Biophysical Chemistry

Short Name: Biophys
Instructors: Mathias Winterhalter
Credit Points: 5 ECTS, elective
Semester:

Course content Interactions between molecules, such as antibody-antigen, enzyme-substrates, receptor-membrane are the base of biological processes. This course introduces current theoretical and experimental tools to quantify such interaction between biomolecules. We begin with a molecular view to introduce the relevant forces and interaction necessary to understand and perform molecular modeling. In a second part we follow a more macroscopic thermodynamic view: substrate binding or partitioning, cooperative effects, transport across membranes to name a few keywords. The third part is devoted to kinetic phenomena and the necessary experimental techniques as relaxation theory, correlation spectroscopy, stopped flow.

560331 – High-throughput screening technology

Short Name: HTS
Instructors: Helge Weingart
Credit Points: 5 ECTS, elective
Semester:

Course content High throughput screening (HTS) is a tool in the discovery of pharmaceutical, chemical, and agricultural compounds. HTS is a main selective tool in big-scale research programs like drug discovery. Methods of HTS are basically methods of analytical biochemistry (photometry, purification, electrophoresis, kinetic assay, radioisotopes, immunoassay, descriptive statistics, regression analysis, etc), that is why HTS course explicitly covers these subjects, because firm knowledge of methods of analytical biochemistry is crucially important for assay design, its validation, and following data analysis and decision making. During the course we also will learn principles of the various detection techniques (light absorption, fluorescence, readioisotope technique). Consequently, the pivot part of the HTS is assay design, where detection techniques are one of the essential parts, and following statistical treatment of the results will lead to making of the decision. Also we will learn physical principles and operational basics of many analytical biochemical instruments used for multi-sample analysis (microplate readers, scintillation counters) as well as consumables for the HTS. In this course we will cover state of the art technologies including automated liquid handling machines (robots) and techniques used in HTS. A focus will be on genetic engineering techniques and screening systems involved. Additionally required automation and engineering approaches will be covered in detail. The goal is to provide students with a background that enables them to successfully implement HTS strategies in real world applications of high-tech industry by mining the created diversity and finding the needle in haystack.

400301 – Computational chemistry and biochemistry

Short Name: CompChem
Instructors: Danilo Roccatano
Credit Points: 5 ECTS, elective
Semester:

Course content The course provides the an introduction to modern methods of computational chemistry, quantum chemistry and molecular simulation, as the most widely used techniques. The quantum chemistry part covers basis sets, the variational principle, Slater determinants, the Hartree-Fock method, an overview of post-Hartree-Fock methods and density-functional theory. The molecular simulation part deals with force fields, molecular dynamics, Monte Carlo and analysis methods. In both areas, applications and examples are chosen from chemistry and biochemistry.

560302 – Design of biomolecules and systems

Short Name: CompChem
Instructors: Danilo Roccatano
Credit Points: 5 ECTS, elective
Semester:

Course content The course is intended to give an overview on theoretical/computational aspects of biological molecule and system design. It provides an introduction to different bioinformatics and molecular modeling methods to study structure, dynamics and function of biomolecular system in solution and at interfaces, molecular recognitions, drug design and virtual screening methods. Practical homeworks and lab tutorials are assigned to deeper the understanding of the methods and tools learn in the theoretical lectures.

xxx – Food and agricultural chemistry

Short Name: FoodChem
Instructors: Nikolai Kuhnert
Credit Points: 5 ECTS, elective
Semester:

Course content The course will address the problems and challenges of how to feed a growing global population.
It will cover lectures on basic nutritional requirements of dietary plants, basics of agricultural practice, the basic science and risks associated with the use of fertilizers, pesticides and genetically modified organisms. The basics of food composition and biochemistry determining nutritional value of selected foods will be covered. Further topics will include methods for food analysis and characterization, legal requirements for food quality control and food safety, aspects of human and animal nutrition, use of alternative food sources, nutraceuticals, industrial processing of food, factors affecting food production and distribution and the effect of agriculture on the environment.

400342 – Organometallic Chemistry

Short Name: OrgMet
Instructors: Gerd Röschenthaler
Credit Points: 5 ECTS, elective
Semester:

Course content Main Group Metal and Transition Metal Organyls (synthesis, bonding and structures, stability, reactions and use), electron deficient systems, sigma- and pi-bonding, sandwich complexes, environmental aspects, heterogenous amd homogenous catalysis, industrially important processes (e.g. Fischer-Tropsch Reactions, Wacker Oxidation, Hydroformylation, Coupling Reactions).

xxx – Fluorine chemistry

Short Name: FChem
Instructors: Gerd Röschenthaler
Credit Points: 5 ECTS, elective
Semester:

Course content This course deals with the different aspects of the chemistry of fluorine-containing organic compounds with an emphasis on physical and chemical peculiarities of organic fluorine compounds, synthesis and reactivity, ecological problems, applications of organofluorine compounds, fluorine-containing diagnostic and pharmaceutical compounds and their mode of action, fluorine-containing liquid crystals for active-matrix displays.

xxx – Introduction to medicinal chemistry

Short Name: MedChem
Instructors: Detlef Gabel
Credit Points: 5 ECTS, elective
Semester:

Course content The course gives an introduction into non-covalent interactions important between drugs and proteins and other drug targets and their physiological consequences. Topics include: Discovery and design of biologically active compounds; mode of action; structure-activity relationships; testing of activity; modifications of lead structures, and combinatorial chemistry.

400312 – Advanced Synthesis

Short Name: AdvSynth
Instructors: T. Nugent
Credit Points: 5 ECTS, elective
Semester:

Course content Building on basic knowledge of functional group transformations and stereochemistry, strategies for the synthesis of complex organic molecules (natural products and pharmaceutical drugs) will be discussed. In this context, the importance of the order and type of transformation (retrosynthetic analysis) required for brevity in synthesis will be stressed. Functional group compatibility, the use of modern reagents, and the control of stereochemistry (chirality) through the use of remote and proximal functional groups vs enatioselective catalysts will be covered.

400341 – Structure and Mechanism

Short Name: StrucMech
Instructors: T. Nugent, W. Nau
Credit Points: 5 ECTS, elective
Semester:

Course content The course will deal with the area of physical-organic chemistry and requires the fundamental knowledge from undergraduate organic and physical chemistry courses, such as Advanced Chemistry AI and BI. The course will cover the following areas: Conformational analysis and molecular mechanics, applications of molecular orbital theory and valence bond, reactive intermediates, spectroscopic methods of studying chemical reactions and reaction mechanisms, and applications to various reaction types. Two special chapters will be dedicated to mechanistic photochemistry and supramolecular chemistry.

Textbooks

- Structure and Mechanism, F. A. Carroll (Brooks/Cole, 1998)

420402 – Organocatalysis

Short Name: OrgCat
Instructors: Thomas Nugent
Credit Points: 5 ECTS, elective
Semester: open

Course content Ten years ago only transition metal or enzyme mediated enantioselective catalysis were pursued. Organocatalysis is now a third option, providing competitive, as well as complementary, solutions for the synthesis of diastereo- and enantioenriched pharmaceutical drugs and natural products. The underlying premise is that low molecular weight chiral organic molecules can be designed and employed for the catalytic activation of achiral starting materials culminating in asymmetric bond formation. The catalysis concepts originate from Bronsted acid and base chemistry and rely heavily on covalent activation and/or strong chiral counter ion effects. When bifunctional organocatalysts are used, weaker (noncovalent) attractive forces (notably hydrogen bonding) become important. Incorporation of these concepts into small all organic catalysts that fine-tuned with the required steric and electronic features allow chemists to control the trajectory, facial approach, and conformation of reacting chemical partners. Students interested in this course will also feel comfortable with the basics of enzymatic pathways (biochemistry), and the overarching principles noted in the first year of organic chemistry. The course will strengthen and expand on those foundations to allow a clearer picture of the critical stereocontrol elements required for natural product synthesis and by extension pharmaceutical drugs.

420xxx – Nanomolecular Materials in Biotechnology

Short Name:
Instructors: Marcelo Fernández-Lahore
Credit Points: 5 ECTS, elective
Semester:

Course content The course is intended to give an overview on nanomolecular materials and systems used in various fields of biotechnology such as product recovery and polishing. Theoretical as well as experimental aspects will be presented in detail including methods for tailoring materials and proteins. Applications and scale-up problems will be explained on selected examples of chemical and pharmaceutical companies. In addition we intend to use a software tool, recently developed at the university Bremen, for modelling, predicting and designing product recovery procedures.

200302 – Elementary Particles and Fields

Short Name: ExpTheoPhys A II
Instructors: B. Hartmann
Credit Points: Lecture, 5 ECTS
Semester: Spring

Course content This course provides an introductory overview about theoretical and experimental aspects of elementary particle physics, quantum field theory and nuclear physics. The Standard Model of particle physics is introduced and experimental and phenomenological aspects of particle physics are discussed. Theoretical topics include gauge theories of the fundamental forces of nature, an introduction to quantum field theory and Feynman diagrams.

200312 – Semiconductor Devices and Advanced Optics

Short Name: ExpTheoPhys B II
Instructors: Veit Wagner and Arnulf Materny
Credit Points: Lecture, 5 ECTS
Semester: Spring

Course content Topics include semiconductors and devices like transistors, LED's, and solar cells for semiconductor devices. The optics part deepens and extends the optics of General Physics. Important issues from modern optics (e.g. dielectric coatings, nonlinear optics, time-domain properties) as well as advanced theoretical descriptions (e.g. Jones vectors, ray matrices) will be introduced.

200331 – Introduction to Computer Simulation Methods

Short Name: IntroCompSimul
Instructors: U. Kleinekathöfer
Credit Points: Lecture, 5 ECTS
Semester: Fall

Course content The introductory course on Computer Simulation Methods discusses a number of practical, numerical solutions for typical problems in the natural sciences. While, for example, the very nature of physics is to express relationsships between physical quantities in mathematical terms, an analytic solution of the resulting formulars is often not available. Instead, numerical solutions based on computer programs are required to obtain useful results for real-life problems. During this course different numerical techniques are introduced such as integration, interpolation, root finding, and solving differential equations which are important tools in any numerical approach. These methods will be applied to a selection of problems including the classical dynamics of particles, traffic simulations, simple electrostatics, random processes, etc. Since the course includes numerous examples and exercises for programming codes, some programming skills in C, Fortran or Python are strongly recommended as prerequisites.

5.2 Seminars and Practical Training

420472 – Current Topics in Physical Sciences

Short Name: CurrTopics
Instructors: Coordinated by one faculty member
Credit Points: 5 ECTS, mandatory
Semester: Fall

Course content The course introduces current topics of physics, chemistry and nanomolecular science. Lectures will be taught by various faculty members according to their expertise. For each field an overview of the scientific background, the motivation and major challenges is provided. This is complemented by an in depth discussion of a specific research topic in each discipline. Each student will select two different fields of chemistry, physics or nanomolecular science, for which (s)he writes a term paper following the scheme of a Ph.D. proposal under the supervision of the corresponding faculty member. Grading is based on the quality of the term papers and attendance.

420412 – Physical Sciences Graduate Student Seminar I

Short Name: GradSemI
Instructors: alternating
Credit Points: 5 ECTS, mandatory
Semester: Spring

Course content The graduate seminar exposes the students of the graduate programs in Physical Sciences to recent developments in the fields. The topics are selected together with the Instructor of Record and need to be presented in front of the other participants.

420511 – Physical Sciences Graduate Student Seminar II

Short Name: GradSemII
Instructors: alternating
Credit Points: 5 ECTS, mandatory
Semester: Fall

Course content In this graduate seminar the students present topics from the Advanced Guided Research I or the Physical Science Research Methods course.

420421 – Physical Sciences Research Methods

Short Name: ResMeth
Instructors: Coordinated by one faculty member
Credit Points: 10 ECTS, mandatory
Semester: Fall

Course content The Practical Training on Research Methods is mandatory for students enrolled in the Physical Sciences Graduate Program. This course exposes the student to different experimental and theoretical techniques employed in the various physics groups at Jacobs University. The Research Training consists of three units of four weeks each from which at least one unit needs to be performed in a theoretical group and one in an experimental group. This course is a prerequisite for the Advanced Guided Research courses.

420462/420461 – Physical Sciences Advanced Guided Research I/II

Short Name: AdvGResI/II
Instructors: Coordinated by one faculty member
Credit Points: 10 ECTS, mandatory, 12 h/week
Semester: Spring/Fall

Course content The Advanced Guided Research courses are mandatory for students enrolled in the Physical Sciences graduate program. During two consecutive courses the students are exposed to a specific research area of physics in-depth. For this the student is required to participate in the research activities of a Jacobs University faculty member that participate in the Physical Sciences graduate program. Typically a continuous project defined by the supervising faculty member is conducted during the consecutive Advanced Guided Research courses. The research can involve experimental and/or theoretical topics. Grading for this course is based on lab performance and the quality of research reports. Furthermore, the Advanced Guided Research courses should enable the students for preparing a M.Sc.. thesis in the 4th semester or entering the Ph.D.. phase.

420522 – Physical Sciences Independent Research and M.Sc. Thesis

Short Name: IndRes
Instructors: Coordinated by one faculty member
Credit Points: 30 ECTS, mandatory, full week
Semester: Spring/Fall

Course content The Independent Research and M.Sc. Thesis denotes a course in which students work independently, but under supervision, on assigned research problems. Learning goals of this course are build on those of all other course. Students need to mobilize everything they have learned so far in order to master the tasks in the Thesis course. The research can involve experimental and/or theoretical topics. The research work of the student has to be summarized in written document, the Master's Thesis. Furthermore the work is presented in a scientific seminar. Grading for this course is based on lab performance and the quality of the Master's Thesis research reports.

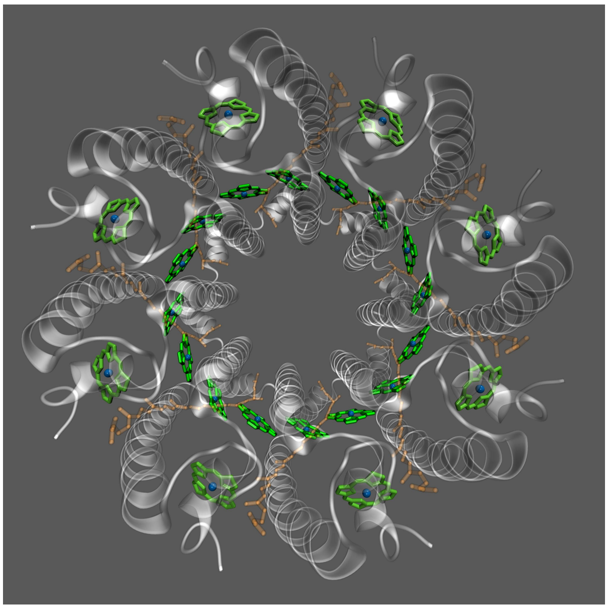


Fig.: Molecular simulations, electronic structure theory, and quantum mechanics are combined to understand the elementary steps in photosynthesis.