Introduction to the MSc Program: Quantum Science

1. Main Idea

The laws of quantum mechanics govern physics at the atomic scale. In combination with concepts of information theory they can be used for technological applications, which significantly advance the current state of the art. This includes secure communication networks, sensors with unprecedented accuracy or fundamentally new models of computation. The development of these quantum technologies is ongoing, its potential has been recognized by relevant authorities, and high-tech companies as well as public funding agencies invest massively in this expanding research area. The current research activities are characterized by a plethora of connections between different disciplines. Indeed, the field is interdisciplinary to the core, combining ideas from mathematics, computer science, and physics. Students planning their career in this field necessarily have to learn key concepts from different subjects, and they need work experience in an interdisciplinary context.

The aim of the MSc program in Quantum Science is to educate young scientists which are dedicated to a career in this field. Key points of the program are:

- The program is interdisciplinary at the border between physics, mathematics, computer science, and electrical engineering. It is open for students with a BSc in any of these four fields.
- The program is international and the language of instruction is English.
- The program introduces novel teaching formats such as project work. It also encourages students to engage in research, e.g., by encouraging them to visit international schools.

2. Addressees

Students with a BSc in

- Physics
- Mathematics
- Computer Science
- Electrical Engineering

3. Overall structure

The overall structure is the following:

- First and second semester: Lectures, seminars, and a mini research project
- Third semester: A preparation project for the MSc thesis (18 CP) and some additional courses (12 CP).
- Fourth semester: MSc thesis.

4. General rules for the curriculum in the first two semesters

The courses can be divided in three groups:

- Interdisciplinary courses for all students (Concepts of QS, Seminar, Mini research project),
- Courses designed to teach quantum theory for non-physicists (Introduction to QT, Quantum Phenomena),
- A pool of further courses comes from the program of the involved departments.

The general ideas behind the curriculum are the following

- Some lectures (Concepts of QS, Mini Research Project, Seminar, in total 21 CP) are mandatory for each student.
- Besides this, there are additional rules for any field. These rules guarantee that:
  - Any student has to attend at least 12 CP outside of the field of their BSc. This ensures an interdisciplinary education.
  - Besides the mandatory interdisciplinary courses, any student has to attend at least 12 CP in the field of quantum science.

4(a). Example curricula for students with a BSc in Physics

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
		Seminar (6CP)		
Electives	Quantum Effects and Quantum Paradoxa (6CP)	Quantum Information Theory (9CP)	Quantum Theory of Light (6CP)	
	Laser Spectroscopy (6CP)		Condensed Matter theory (6CP)	
	Classical Complexity Theory (6CP)	Quantum Complexity Theory (6CP)		
	Deep Learning (6CP)			
CP Sum	30	30	30	30

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
		Seminar (6CP)		
Electives	Quantum Theory of Light (6CP)	Experimental Quantum Optics (9CP)	Quantum Effects and Quantum Paradoxa (6CP)	
	Laser Spectroscopy (6CP)		Nano Optics (6CP)	
	Nanotechnology (6CP)			
	Photonics I (6CP)	Photonics II (6CP)		
CP Sum	30	30	30	30

4(b). Example curricula for students with a BSc in mathematics

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
	Quantum Phenomena (6CP)	Seminar (6CP)		
	Introduction to QT (9CP)			
Electives		Quantum Information Theory (9CP)		
	Algorithmic Algebra (9CP)	Advanced Algebra (9CP)	Functional Analysis (9CP)	
CP Sum	30	33	27	30

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
	Quantum Phenomena (6CP)	Seminar (6CP)		
	Introduction to QT (9CP)			
Electives		Theoretical Particle Physics (9CP)		
	Functional Analysis (9CP)	Nonlinear Optimization (9CP)	Advanced Functional Analysis (9CP)	
CP Sum	30	33	27	30

4(c). Example curricula for students with a BSc in Computer Science

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
	Quantum Phenomena (6CP)	Seminar (6CP)		
	Introduction to QT (9CP)			
Electives		Quantum Information Theory (9CP)	Quantum effects and quantum paradoxa (6CP)	
	Algorithmic Algebra (9 CP)	Statistical Learning Theory (6 CP)	Classical Complexity Theory (6CP)	
CP Sum	30	30	30	30

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
	Quantum Phenomena (6CP)	Seminar (6CP)		
	Introduction to QT (9CP)			
Electives	Classical Complexity Theory (6 CP)	Quantum Complexity Theory (6CP)	Quantum effects and quantum paradoxa (6CP)	
	Deep Learning (6 CP)	Recent Advances in ML (6CP)	Compressive Sensing (6CP)	
CP Sum	33	27	30	30

4(d). Example curricula for a students with a BSc in Electrical Engineering

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
	Quantum Phenomena (6CP)	Seminar (6CP)		
	Introduction to QT (9CP)			
Electives	Lab Course Physics (9CP)	Experimental Quantum Optics (9CP)	Laser spectroscopy (6CP)	
		Photonic Devices (6CP)	High Frequency Engineering (6CP)	
CP Sum	30	30	30	30

	First Semester	Second Semester	Third Semester	Fourth Semester
Mandatory	Concepts of QS (6CP)	Mini Research Project (9CP)	Preparation for MSc Thesis (18CP)	MSc Thesis (30CP)
	Quantum Phenomena (6CP)	Seminar (6CP)		
	Introduction to QT (9CP)			
Electives	Compressive Sensing (6CP)	Photonic Devices (6CP)	Nanotechnology (6CP)	
	Photonics I (6 CP)	Photonics II (6CP)	Experimental methods of quantum and nano optics (6CP)	
CP Sum	33	27	30	30

5. Structure of the third and fourth semester

Third semester:
The third semester is intended mainly to be a preparation for the MSc thesis. Therefore, the students take a preparation project for the MSc thesis, which is given to them by the chosen supervisor of the Msc thesis. In addition, the students have to choose 12 CP of courses in this semester. This may also contain internships in industry or the attendance of research schools.

Fourth semester:
The fourth semester is dedicated to the MSc thesis.