Advanced Quantum Mechanics

Identification number	Workload	Credits	Term of studying	Frequency of occurrence	Duration
MN-P-QMII	270 h	9 CP	1st Semester	Every winter term	1 Semester

1	Type of lessons	Contact times	Self-study times	Intended group size
	a) Lecture	56 h	84 h	15–20 students per problem class
	b) Problem Class	28 h	84 h	
	c) Preparation for exam	---	18 h	

2 **Aims of the module and acquired skills**

Building on the foundational exposition of quantum mechanics in the B.Sc. physics curriculum, this course teaches the parts of advanced quantum mechanics that are required knowledge for doing master thesis research in experimental or theoretical physics. In particular, the course develops the basic formalism of quantum scattering theory, arguably the main tool to analyze fundamental physics experiments at high and low energies. The part on the Dirac equation, governing all fundamental matter fields, discusses the novel features that arise when quantum mechanics is combined with the theory of special relativity; here, students learn where 'spin' comes from, and they get an outlook on the origins of quantum field theory. The part on second quantization introduces the formalism needed for the many-body physics of atomic nuclei and condensed matter systems.

3 **Contents of the module**

1. Scattering theory
   - differential cross section
   - method of partial waves and scattering phases for systems with spherical symmetry
   - optical theorem, Lippmann-Schwinger equation, Born approximation
   - time-dependent scattering theory, Moeller operators
   - scattering matrix, multichannel scattering
2. The formalism of second quantization
   - construction of the Fock space for fermions and bosons
   - second quantization of one- and two-body operators
   - vacuum state and normal ordering
   - quantum theory of the free electromagnetic field
3. Relativistic quantum theory
   - Dirac equation, invariance properties (parity, time reversal, charge conjugation)
   - hole interpretation of the positron, nonrelativistic reduction
   - Pauli equation, spinors
4. Specialized topic in advanced quantum mechanics, for example, applications of group theory (theory of angular momentum and spin), the standard model of particle physics, or quantum information theory.

4	Teaching/Learning methods Besides the teaching in lectures, the self-study based on books and lecture notes plays an important role. The students work individually on problem sets. In discussions with others and in the problem classes, they learn to solve challenging problems in a team and to present their approaches and results.
5	Requirements for participation Classical theoretical physics (mechanics and electrodynamics), basic quantum mechanics (as taught in a one-semester theoretical physics course on quantum mechanics).
6	Type of module examinations The module is passed by passing a written exam, which is held during the semester and is offered again at the beginning of the following semester. To be accepted for the written exam, students must actively participate in the problem class, solve the homework problems and register for the exam.
7	Requisites for the allocation of credits The module is passed by passing a written exam. The grade given for the module is equal to the grade of the written exam.
8	Compatibility with other Curricula As elective subject in other M.Sc. programs.
9	Significance of the module mark for the overall grade The weight of the module is $9/111 \approx 8.1$ %.
10	Module coordinator M. Zirnbauer
11	Additional information Literature: Sakurai, Modern Quantum Mechanics (Addison-Wesley), Schwabl, Advanced Quantum Mechanics (Springer) Version: 06.11.2017 MZ