Module	***Condensed Matter Theory***
Code	71659
Instruction language	English
ECTS credits	6
Credit hours	5
Duration	1 semester
Cycle	Irregularly
Coordinator	Dean of Physics Studies
Lecturer	Dr. Björn Kubala, Prof. Joachim Ankerhold,
Allocation to study programmes	Physics M.Sc., elective module, 1st or 2nd semester
Formal prerequisites	None
Recommended prerequisites	Quantum Mechanics, Solid State Physics, Thermodynamics/statistics
Learning objectives	Students who successfully passed this module • understand methods and concepts of the description of open classical and quantum mechanical systems • understand basic differences in the dynamics of classical and quantum mechanical open systems • possess advanced knowledge of quantum statistics • are able to read relevant original literature to present it and know current experimental realizations
Syllabus	There are several courses with different content, which are alternately offered for this module. **Quantum Mechanics on Macroscopic Scales** The course explores theoretical and experimental developments in solid state physics over the past twenty years that describe and access quantum mechanical properties on growing length scales and with growing complexity. Low-temperature properties of condensed matter systems are governed by quantum mechanics. Many-body effects are crucial and may lead to completely new phenomena, determined by the dynamics of new collective degrees of freedom. In superconducting devices, the quantum dynamics of these collective variables can be observed, manipulated, and exploited for applications, e.g., for quantum-information technologies. In this course, we will study the physics underlying such devices and introduce tools for their analysis and description. • Introduction • Macroscopic quantum oscillator • Nonlinear oscillator: Josephson junction • From artificial atoms to circuit-QED • Basics of open quantum systems: master equation • Single charge transfer • From circuit-QED to Josephson photonics

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Quantum Transport and Topology

In this lecture, we want to explore quantum effects in transport:
From the early experimental observation of conductance quantization and the theoretical picture of Landauer of "transport as transmission" to the recent focus on topological properties and materials, such as topological insulators.

- Tunneling and Scattering Matrix Theory
- Landau-levels and the Integer Quantum Hall Effect
- Fractional Quantum Hall Effect, composite fermions
- Majorana fermions and the Kitaev chain
- Topological quantum numbers

Decoherence and dissipation:

- Classical Langevin equation, Fokker-Planck equation
- Response functions, fluctuation dissipation theorem
- Master equations, Redfield equation
- Born-Markov approximation
- System + bath model
- Harmonic oscillator: exact description
- Correlation functions
- Path integrals, reduced density operator
- Dissipative tunnelling
- Real-time dynamics as a path integral
- Paths minimal effect

Collective quantum phenomena:

- Second quantization
- Many-body theory, quantum statistics
- Superconductivity (BCS theory)
- Bolgoliubov-de Gennes equations
- Josephson effect and superconducting circuits
- Integral and fractional quantum Hall effect
- Laughlin wave function and Chern-Simons theory
- Bose-Einstein condensation (BEC)
- BEC atomic gases
- Gross-Pitaevskii equation
- Elementary excitations

Many-body theory and transport:

- Second quantization
- Linear response theory
- Green functions
- Concept of quasiparticles
- Perturbation theory at T = 0
- S-matrix, Wick's theorem
- Feynman diagrams, Dyson equation
- Exactly solvable models
- Approximation methods: Hartree-Fock
- Hubbard model, the Kondo model
- Landauer and Landauer-Büttiker formalism
- Meir-Wingreen equation

Literature	**Quantum Mechanics on Macroscopic Scales** • Michel Devoret, Quantum fluctuations in electrical circuits, Les Houches Lectures, with Uri Vool, arXiv:1610.03438

	• Tero T. Heikkilä,The Physics of Nanoelectronics: Transport and Fluctuation Phenomena at Low Temperatures • P. Breuer and F. Petruccione, The Theory of Open Quantum Systems, Oxford University Press **Decoherence and dissipation:** • Weiss, Quantum Open Systems, World Scientific • Breuer, Petruccione, The Theory of Open Quantum Systems, Oxford • Kleinert, Path Integrals in Quantum Mechanics etc., World Scientific **Collective quantum phenomena:** • De Gennes, Superconductivity of Metals and Alloys, Westview Press • Tinkham, Introduction to Superconductivity, Krieger Publishing • Yoshioka, The Quantum Hall Effect, Springer • Pitaevskii, Stringari, Bose Einstein Condensation, Oxford University Press **Many-body theory and transport:** • Mahan, Many-Particle Physics, Plenum Press • Nolting, Grundkurs Theoretische Physik 7, Springer
Teaching and learning methods	Lecture (3 hours per week) Exercise (2 hours per week)
Workload	45 hours lecture (attendance time) 30 hours exercise (attendance time) 105 hours self-study and exam preparation Total: 180 hours
Assessment	Written or oral examination. A prerequisite for the participation in the examination is an ungraded course achievement. Form and scope of the examination and of the course achievement are determined and notified by the lecturer at the beginning of the course.
Examination	12370 Condensed Matter Theory (precourse) 12369 Condensed Matter Theory
Grading procedure	The module grade is the examination grade.
Basis for	Research in the field of Condensed Matter