Course Package

Materials Physics – 1A + 1B

Name module	Materials Physics - 1A + 1B
Educational programme	MSc Applied Physics
Period	First semester (block 1A+1B)
Study load	30 ECTS

Materials Physics			
block 1A	**block 1B**	**block 2A**	**block 2B**
Electives: choose 15 EC	***Electives: choose 15 EC***		
AMM- Characterization **193700010** (5 EC)	***Theoretical Solid State Physics** **193510040** (5 EC)		
Quantum Information **202100078** (5 EC)			
Quantum Mechanics 2 **202200093** (5 EC)	**Intro. to High Energy Physics** **193530040 (**5 EC)		
Nanophysics **193530010** (5 EC)	**Nano-Electronics** **193400141** (5 EC)		
Intr. to Superconductivity **193530000** (5 EC)	**Applications of superconductivity** **201100214** (5 EC)		

General required preliminary knowledge: Completed Bachelor's (Applied) Physics; Hilbert Spaces; and Quantum Mechanics courses (i.e. introductory quantum mechanics and linear algebra); Theory of solid state physics; Applied Quantum Mechanics; Introduction to Solid State Physics; Nanoscience; Basics of physical chemistry; Organic and Inorganic Chemistry; Materials Science and Molecular Biology; 3rd year of studies and beyond; Introduction to Superconductivity; first year's math courses B-TN.

* Mandatory previous knowledge: Quantum Mechanics

Block 1A

Electives: choose 15 EC

193700010 - **AMM- Characterization**

In this module a palette of state-of-the-art characterization techniques to investigate structure and properties of nanostructures will be introduced and applied. The module consists of 3 courses: Surface characterization (35 %), X-ray diffraction (30 %) and Microscopy and Spectroscopy (35 %). Recent publications on metal halide perovskite photovoltaics will be used as case study to illustrate the potential and complementarity of all techniques discussed in this module.

202100078 - Quantum Information

One of the most exciting developments in physics in the last decade has been the development of quantum computing systems of increasing size and complexity. The crowning achievement (for the moment) has been the construction and operation of the first quantum devices able to outperform a classical computer at a well-defined computational task. Such so-called ‘quantum supremacy’ is the first milestone in the worldwide drive to build universal, large-scale quantum computers.

This course will teach the fundamentals of quantum information theory necessary to understand these and other recent developments in the quantum world.

The course will consist of four parts:

In the first part, we will slightly ‘upgrade’ the mathematical and theoretical abstraction level at which we do quantum mechanics and linear algebra, taking as our starting point where we left off in the Hilbert Spaces course in the bachelor. We will treat operator exponents, the singular value decomposition, density matrices, Pauli operators and density matrices.

In the second part, we will use this new-found knowledge to discuss many of the famous basic concepts and experiments in quantum information theory, including entanglement, quantum teleportation, the Einstein-Podolski-Rosen experiment, Bell tests, and so on. We will also briefly discuss open quantum systems and the representation of noise in quantum systems.

In the third part, we will bring some computer science in the mix. We will discuss quantum computers, including the Solovay-Kitaev theorem, quantum error correcting codes, the threshold theorem, Grover’s and Shor’s algorithm, the stabilizer formalism, the Gottesman-Knill theorem and quantum simulation.

Finally, we will focus on current developments in experimental quantum information processing. We will discuss the notion of a quantum advantage, NISQ, sampling problems, and the prospects for near-term applications of quantum systems. We will also discuss experimental progress on the various experimental computing platforms.

The course material will consist of the book “Quantum Computation and Quantum Information: 10th Anniversary Edition, Nielsen and Chuang”. Note that there are different editions of this book, which have discrepancies in page numbering and assignment numbering between them. Please make sure you purchase the 10^{th}-anniversary edition as noted above.

202200093 - **Quantum Mechanics 2**

In this course, we ask the question: How can we apply the fundamental principles of quantum mechanics to systems beyond the hydrogen atom and to systems that interact with electromagnetic radiation? We start by recapping the structure of the solution of the hydrogen atom and define the ingredients that are needed to describe systems that consist of more than one electron and proton: coupling of angular momenta, symmetries, and particle-particle interactions. The latter are neglected in this course and will be introduced elsewhere. The former two and their intimate relationship with each other will be discussed in detail. This will then allow us to gain an approximate understanding of the periodic table of elements and even of the electronic structure of some molecules.

We will then use the concept of perturbation theory (time-independent and time-dependent) to understand effects like the fine structure of the hydrogen atom and how matter interacts with electromagnetic radiation, deriving Fermi’s famous Golden Rule. Finally, we will look at scattering problems and approximate ways for solving them with many important applications in diverse areas such as X-rays and particle physics.

193530010 – Nanophysics

In this course, we focus on low-dimensional systems with typical length scales in the range of 1-100 nm. At this small length scale, quantum mechanical phenomena play a dominant role in the physics of devices. Prominent topics are quantum electronic transport, both coherent and incoherent, Coulomb blockade, and the quantum Hall effect. The physical description of these phenomena is illustrated by examples from current research in nanophysics. Often we revise, exchange, or add new timely topics to this course. During the last few years, we have added the following topics: graphene, 2D Dirac materials, moiré materials/twisted materials, and quantum spin Hall effect.

193530000 - Introduction to Superconductivity

- The course treats (among other topics):
- Basic principles of superconductivity and superfluidity
- Quantum phenomena in these 'super-states'
- Vortex physics in type II superconductors
- Josephson junctions
- Superconducting materials
- Introduction to superconducting applications

Block 1B

Electives: choose 15 EC

193510040 - **Theoretical Solid State Physics**

This course builds on Introduction to Solid State Physics, treating the material in more detail and extending the scope to cover a number of additional topics:

- Tight-binding method
- Semiclassical Transport Theory
- Magnetism

The emphasis of the course is on operationalizing the theoretical material treated in the lectures by doing homework. This is corrected and the mark contributes to the final mark.The course is based upon the following chapters of "Solid State Physics" by Ashcroft & Mermin, supplemented with lecture notes:

§1 The Drude Theory of Metals

§2 The Sommerfeld Theory of Metals

§3 Failures of the Free Electron Model

§10 The Tight-Binding Method

§12 The Semiclassical Model of Electron Dynamics

§13 The Semiclassical Theory of Conduction in Metals

§14 Measuring the Fermi Surface

§15 Band Structure of Selected Metals

§16 Beyond the Relaxation-Time Approximation

§17 Beyond the Independent Electron Approximation

§31 Diamagnetism and Paramagnetism

§32 Electron Interactions and Magnetic Structure

§33 Magnetic Ordering

193530040 - **Introduction to High Energy Physics**

- Big bang and elementary particles: 'macroscopy' versus 'fermiscopy',
- Theory of special relativity and relativistic kinematics,
- Particles, waves and fields,
- The atomic nucleus and particle decay,
- Rutherford scattering and the theory of scattering,
- Electromagnetic, strong and weak interactions,

- Matter – antimatter asymmetry
- Baryons en mesons: the quark model,
- Particle accelerators,
- W± en Z0 : carriers of the weak force; experiments,
- The Standard Model and the discovery of the top quark and Higgs boson
- Structure of the proton: the quark-parton model; experiments,
- Electron-positron annihilation; precision measurements,
- Particles and matter: detection principles,
- Detectors in high energy particle and astro-particle physics.

193400141 - Nano-Electronics

Nanoelectronics comprises the study of the electronic and magnetic properties of systems with critical dimensions in the nanoregime. Quantum electronics, spin electronics, organic electronics and neuromorphic electronics form important subfields of nanoelectronics and are being discussed in this course. Quantum electronics and neuromorphic electronics will be treated in-depth. For those who want to get a thorough introduction into the new exciting directions that will contribute to future electronics, this course is indispensable. Recommended for MSc students Nanotechnology. Applied Physics and Electrical Engineering. The course consists of lectures, assessments and a project. In the project, a small research proposal is written on a theme related to the course. The proposal is presented in written and oral form and graded by the lecturers.

201100214 - Applications of Superconductivity

Superconducting materials: Metallic (NbTi, Nb3Sn, MgB2), ceramic (ReBCO, BSCCO) and pnictide (BaFe2As2) materials; Superconductor shape and processing (composite wires and tapes); Structure and function of superconducting cables.

Physical and technological issues: Transport properties and characteristic critical currents and current densities; Thermal-electro-magnetic stability criteria; Magnetization and Alternating Current losses; and the dependence all of these issues on temperature, magnetic field and mechanical strain.

Practical applications: High-field magnets for e.g. High Field Magnet facilities, NMR and MRI medical diagnostics; Magnets for particle accelerators (like the LHC and FCC at CERN) and for medical accelerators for proton therapy; Particle detector magnets; Magnets for Plasma Fusion reactors (ITER, W7X, DEMO); Electrical power applications (motors, generators and cables for current transport).