Course Package

Materials Physics – Q1

Name module	Materials Physics - Q1
Educational programme	MSc Applied Physics
Period	First semester (Quartile 1)
Study load	15 ECTS

Materials Physics			
Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
Electives: choose 15 EC			
Characterization **193700010** (5 EC)			
Quantum Information **202100078** (5 EC)			
Quantum Mechanics 2 **202200093** (5 EC)			
Nanophysics **193530010** (5 EC)			
Introduction to Superconductivity **193530000** (5 EC)			

Suitable for: 3rd year student (or completed) the Bachelor of (Applied) Physics.

Required preliminary knowledge on bachelor level: Quantum Mechanics; Linear Algebra; Hilbert Spaces; Calculus; Introduction to Solid State Physics.

Electives: choose 15 EC

193700010 - 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 (Landauer-Büttiker formalism), coherent and incoherent transport, Coulomb blockade, and the integer quantum Hall effect. We also discuss the electronic band structure and topology of two-dimensional (2D) materials and twisted 2D (moiré) materials. We will elaborate on spin-orbit induced band inversion (the Kane-Mele model), the bulk-boundary principle, Berry phase, Berry curvature, Berry connection and Chern number for graphene and graphene-like materials. We also discuss the quantum spin Hall effect, the quantum valley Hall effect and Wigner crystallization in two-dimensional topological insulators and/or twisted bilayer graphene. The physical description of these phenomena is often illustrated by examples obtained from scientific articles.

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

Please note: these packages are not fixed. They serve as an example of what you are able to select. It may be possible for you to make changes if you would like to do so.

The modules are tentative and subject to change. Please check the website *regularly.*