Course Package

Optics – Q1

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

Optics			
Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
Electives: choose 15 EC			
Quantum Mechanics 2 **202200093** (5 EC)			
Biophysical Techniques & Molecular Imag. **193640020** (5 EC)			
Fundamentals of Photonics **202200044** (5 EC)			
Quantum Information **202100078** (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; Optics (theory).

Electives: choose 15 EC

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.

193640020 - Biophysical Techniques & Molecular Imaging

Fundamentals fluorescence and vibrational transitions, related parameters; instrumentation spectroscopy and microscopy (widefield, confocal, fluorescrence, Raman); fluorophores (intrinsic, extrinsic, fluorescent proteins) and labeling strategies; monitoring molecular interactions (anisotropy, MST, FCS, quenching), molecular motion (FRAP, FLIP, FCS); single molecule spectroscopy; superresolution microscopy (single molecule localization, STED); accessing molecular structure (fluorescence based, electron microscopy).

202200044 - Fundamentals of Photonics

The wave nature of electromagnetic radiation forms the basis of high-speed internet and wireless communications, which are an integral part of our society. In this course we build upon and extend the wave concept of light as introduced in the bachelor Optics course. We revisit the wave equation and introduce the concept of Green's functions. Also, we will consider light-matter interaction in various configurations. We discuss the Lorentz and Drude model to explain the origin of refractive index of materials, and what surface plasmon polaritrons are. We also investigate how particular distributions of the refractive index, modify light propagation. This includes photonic crystals, waveguiding and scattering of light. We discuss the use of the transfer matrix method to model light propagation through a stack of thin films. The students will be introduced to the concept of wavefront propagation and this concept is used to discuss the point spread function and resolution of an imaging system. We will also illustrate how wavefront propagation has been used to solve various optical problems encountered in industry. Finally, we discuss how the wavelength dependent refractive index will modify the propagation of a (short) light pulse by introducing the concept of chirp filters.

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.

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.*

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 10th anniversary edition as noted above.

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