Internship –12 ECTS

SEMESTER 3

Specialisation courses –12 ECTS

✓ Quantum optics (3 ECTS)

- Phenomenological approaches to laser-matter interaction
- Semi-classical approach: density matrix. Evolution in the presence of relaxation, pilot equation.

Perturbative treatment and susceptibility.

- Quasi-resonant interaction in two-level systems
- Optical Bloch equations. Coherent transients. Ultra-high resolution spectroscopy. Ramsey Fringes.
- Quantum description of the free electromagnetic field: Quantification of radiation, stationary states of radiation, coherent state. Spontaneous emission. Photon statistics.
- Interaction between a two-level system and a quantum field: Hamiltonian and interaction process. Dressed atom method.
- Photodetection signals

✓ Light manipulation of matter (3 ECTS)

Laser cooling and trapping: cold atoms

- Radiative forces
- Slowing down, cooling, trapping atoms by lasers
- Magnetic trapping and evaporative cooling, Bose-Einstein condensation
- Applications: Metrology, Quantum Simulators .....

Optical tweezers
Structuration of matter by light
Interaction of structured light (vortex beams…) with structured matter.
Light manipulation of vortex matter.

✓ Nanophysics (3 ECTS)

- What is Nanophysics? Introduction to the physical properties of nanosystems. « Top-Down » and « Down-Top » approaches.
- Electronic states and bands structures of nanoscale materials. 2D, 1D and quantum dots structures.
- Optical properties of nanoscale materials. Size-dependent optical properties and electromagnetic interactions.

-Nanoelectronics. Quantum transport, electron interference phenomena at nanoscale. Coulomb blockage and single electron transport.
-Quantum Hall effect in two dimensional electron gases.

-Graphene. Electronic band structure. Effective model at low energy (Dirac equation). Klein tunneling. Optical properties of graphene.
-Superconductivity at the nano-scale. Josephson junctions and superconducting nano-electronics.
-Spintronics. Giant magnetoresistance. Magnetic moment manipulation via the electric current.

Lab courses:
Magnetism and light interaction in solid state/ Light and magnetism in quantum materials
Light and superconductivity
Dirac materials and topological insulators

Attosciences and related technologies (3 ECTS)

- Introduction and motivations of attosecond physics
- Generation of high order harmonics and attosecond pulses
- Temporal characterization of attosecond pulses
- Harmonic spectroscopy
- Application of attosecond pulses: measurement of delays to photoionization
- Application of attosecond pulses: attosecond transient absorption spectroscopy
- Experimental tools: vacuum, XUV spectroscopy, particle spectroscopy
- Theoretical tools: semi-classical modeling of attosecond physics.

Advanced statistical physics (3 ECTS)

Many processes in physics appear to behave randomly. The occurence of randomness is intrinsically linked to thermal or quantum fluctuations. For instance, a colloid in a liquid undergoes a continuous random motion known as Brownian motion which is the simplest form of a continuous time stochastic process.

We will see how stochastic processes can be used to model a huge variety of processes from physics, chemistry and biology (and even economics where they are used to study stock market movements).

The probability distributions of many stochastic processes obey the Fokker-Planck equation. This equation can be used to find the steady state distribution or other quantities such as survival probabilities.

Discrete systems, for instance Ising spins or particles on a lattice, also have dynamics which can be described by Markov chain. Physically the systems evolution in the future only depends on its current state and not all of its past history. The idea of a Markov chain is vital for numerical simulation of discrete interacting systems, where we cannot compute the thermodynamic properties analytically, and is employed in Monte Carlo simulations.

The idea of this course is to give a general introduction to stochastic processes which will be useful in a wide variety of scientific areas for both pure and applied research.

1 Stochastic calculus and Langevin equations
1.1 Discrete time continuous space stochastic processes
1.2 The Ito Stochastic Calculus
1.3 Examples of Stochastic Differential Equations - underdamped Brownian motion and taking the over damped limit
1.4 The Generator and the Forward Fokker-Planck Equation
1.5 Links with physical descriptions of diffusion, Fick's law.
1.6. First passage times.
1.7 Transport properties of a colloid in spatially varying potential.
1.8. Reduction of underdamped equations to over damped equation - the method of projection operators.
1.9 Stochastic processes in Fourier space - correlation functions.
1.10 Partially damped simple harmonic oscillator in the Langevin treatment, fluctuation dissipation theorem and Kramers Kronig Theorem.

2 Markov chains
2.1 Basic definitions and applications
2.2 Master equations for Markov chains
2.3 Detailed balance and the principle of Monte Carlo simulations for equilibrium statistical physics systems, sampling questions for Monte Carlo simulations
2.4 Glauber solution for the dynamics of 1d Ising Model
2.5 Correlation and response functions for Markov chains - generalised proof of fluctuation dissipation theorem -applications, for example conductivity of metals

✓ Optics of nanomaterials (3 ECTS)

- Introduction to optical spectroscopy and photophysics of molecular systems.
- Metallic nanostructures: Optical properties of noble metals and plasmonic nanostructures, dielectric confinement, applications
- Semiconductor nanostructures, quantum confinement, consequences of the density of states on the optical properties.
- Semiconductor quantum dots and colloidal nanocrystals: photophysics and applications
- 1D quantum systems, Carbon nanotubes
- 2D quantum materials
- Single photon sources