Course Package

Fluid Physics – 1A + 1B

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

Fluid Physics			
block 1A	**block 1B**	**block 2A**	**block 2B**
Physical Biology **202001414b** (5 EC)	**Physics of Bubbles** **193572010** (2,5 EC) **Ion Transport in Fluids** **201800327** (2,5 EC)		
Advanced Colloids and Interfaces **201800083** (5 EC)	**Mathematical and Numerical Physics** **201900080** (5 EC)		
Advanced Fluid Mechanics **193570010** (5 EC)	**Turbulence** **193580010** (5 EC)		

<u>Required preliminary knowledge:</u> Completed Bachelor's (Applied) Physics and Basic Fluid Mechanics; Basic knowledge in biology (high school level) and thermodynamics (BSc level) is assumed to be present; Physics of fluids and Calculus 2 or equivalent knowledge. Desirable: Heat and mass transfer and a level of mathematics, or comparable to a bachelor TN; Engineering Fluid Dynamics; Transport Phenomena, or similar introductory course in fluid mechanics; Bachelor Applied Physics; or Bachelor Mechanical Engineering.

Block 1A

202001414 - **Physical Biology**

The complex behaviour of cells and bio-molecules cannot be fully understood without deep physical insight, triggering an increasing interest in physical biology. Generic physical concepts have given quantitative insight into how muscle cells convert the chemical energy of ATP into movement and into how DNA can replicate itself during cell division. In this course, we will discuss both the biochemistry and basic physical principles that help us understand and quantitatively describe biological phenomena and processes occurring in cells.

After an introduction into cellular and molecular biology, you will learn how the confluence of thermal, mechanical, chemical and entropic forces make the behaviour of cells and biological macromolecules so different from our everyday experience. Topics include: the central dogma in molecular biology, cellular transport mechanisms, different forms of intracellular signalling mechanisms, , diffusion, entropic forces, self-assembly, biopolymer elasticity, and molecular machines. The course consists of lectures, self-study, and 15 min presentation and peer review by students on a self-chosen subject related to the latest developments in one of the course topics.

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201800083 - Advanced Colloids and Interfaces

Description of colloids, surfaces and interfaces. All kinds of interfaces between different phases are treated. Thermodynamic descriptions of these interfaces are deduced. Several techniques for characterizing interfaces are discussed. During contact hours, the contents of will be presented and discussed, and exercises will be made and discussed. For each topic, a case assignment will be offered. Topics include:

- Lifshitz-van der Waals Interactions
- Polar/Acid-Base Interactions
- Wetting and Contact Angles
- Electrostatics
- DLVO and XDLVO interaction
- Electrokinetic Phenomena
- Electrostatic and Polymeric Stabilization of Colloids
- Colloidal Phenomena (Marangoni-Effect, Ouzo effect, etc.)

193570010 - Advanced Fluid Mechanics

Derivation of the conservation laws, vorticity, potential flow in 2D and 3D, conformal mapping and 2D flow, Zhukovsky Airfoil, waves, shallow water equations, flow at low Reynolds numbers, Stokes and Oseen solutions, Hele-Shaw flow, flow at high Reynolds numbers, boundary layers, self-similarity, hydrodynamic stability.

The objective of this course is to acquire a firm base in classical fluid mechanics. The emphasis is on the derivation of the governing equations, their analytical solutions, and their physical implications. Advanced Fluid Mechanics will serve as an introduction to the basic equations and phenomena needed in "Turbulence" , "Experimental Techniques in Physics of Fluids", “Physics of Bubbles”, “Capillarity Phenomena” and various specific lectures on e.g. acoustics, granular flow, computational fluid dynamics, etc.

Block 1B

193572010 - Physics of Bubbles

The Physics of Bubbles course treats the physics of single bubble and describes the behavior of multiple bubbles and bubble clouds. The course treats the forces on bubbles, the acoustics of bubbles and bubble clouds, microstreaming and jets due to bubble oscillation, cavitation and bubble collapse. The course includes lectures on the use of bubbles in medical imaging and in molecular imaging with ultrasound. Also therapeutic applications of bubbles are discussed, along with bubbles in process technology and bubble formation and bubble dynamics in microfluidic devices and nanotechnology.

201800327 - Ion Transport in Fluids

Starting from the electrochemical potential, the Nernst-Planck equation will be derived and then used to understand the relative contribution of electromigration and diffusion. The validity of assuming electroneutrality in a fluid phase is discussed and investigated by introduction of the Poisson equation. In double layers and interfaces, the potential and ion distributions can be studied further. Next, the effect of fluid transport on ion transport and vice-versa will be introduced by combining the Poisson-Nernst-Planck equations with the Navier-Stokes equations. From this, electrokinetic mechanisms such as electro-osmosis can be derived. Finally, the use of these frameworks in relevant industrial procesess where ion transport plays a crucial role is explored.

201900080 - Mathematical and Numerical Physics

The course consists of three parts; all students take the first part, and then choose between either a mathematical or a numerical track. These tracks consist of two parts, each lasting approximately 2 weeks. There is a possibility to switch between the two tracks halfway (after approx. 6 weeks).

Each part is introduced via one or more lectures, accompanied by some written material or reference to accessible material. Students work on assignments related to the topic and produce a written report on every part of the course. At the end of the course, students chose a topic to be presented by means of a poster during a seminar. Below we briefly summarize the topics of the various parts of the course.

Part 1 (2.2EC; approximately 4 weeks) deals with phase separations, starting from an analytical description, followed by a numerical treatment.

Numerical track:

Part 2 (1.1EC; approximately 2 weeks) focuses on physics problems that can be mapped onto solving sets of (non-linear) equations numerically. One selection of problems revolves around solving the Poisson-Boltzmann equation. The numerical methods covered are the classical techniques of LU decomposition, fixed-point iteration, Jacobi and Gauss-Seidel iteration, and over-relaxation. A second set of problems focuses on the self-consistent polarization field and its effect on the transport gap in molecular crystals. Convergence acceleration is vital for solving this problem. For this, a special technique will be introduced, called Pulay iteration. The students will enjoy programming these algorithms and solving the physics problems themselves without much need for black-box routines.

Part 3 (1.1EC; approximately 2 weeks) focuses on physics problems that can be mapped onto (non-linear) eigenvalue equations. One example is the non-linear Schrödinger equation, which can be used to describe polaron particles in condensed matter, or soliton waves in non-linear optics. A second example is the constrained Schrödinger equation that describes the formation of a Cooper pair in a superconductor. A third example comprises the quantum rotations of the water molecule, which has implications for its thermodynamical properties, i.e. ortho-water and para-water. General numerical approaches for solving eigenvalue problems will be discussed and applied, such as (inverse) power iteration, Rayleigh quotient iteration and QR iteration. The students will enjoy programming these algorithms, learn to think inside the boxes, and solve some interesting physics problems.

Analytical track:

Part 2 (1.1EC; approximately 2 weeks) focuses on the study of phase transitions. Techniques: Mean field, expansions in temperature, dimensions, degrees of freedom, renormalization group. General techniques: complex analysis, counting (loop expansions, generating functions, Pade)

Part 3 (1.1EC; approximately 2 weeks) focuses on the study of group theory and symmetry in physics. Techniques: determining groups and symmetries, Lagrangians, Euler-Lagrange, variational principles, gauge symmetry, Maxwell and weak/strong interactions, symmetry breaking, Noether's theorem, Goldstone particles, Higgs particle.

Seminar (0.6EC): A poster will be prepared on one of the topics worked on during the course. During a closing seminar the poster will be presented to all students and teachers.

193580010 - **Turbulence**

Below is an itemized list of the main topics that will be addressed during the course.

1. Equations of fluid motion
   - Navier-Stokes equations
   - The role of pressure
   - Transformation properties of Navier-Stokes equations
2. Statistical description of turbulent flows
   - Mean, standard deviation, skewness, kurtosis
   - Probability Density Function (PDF)
   - Energy spectrum

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- Structure functions
- Statistical stationarity
3. Mean flow equations
   - Reynolds Averaged Navier Stokes equations
   - Reynolds stresses
   - Closure problem in turbulence
4. Free shear flows
   - Boundary layer equations
   - Self-similarity
5. The scales of turbulent motion
   - The energy cascade and Kolmogorov hypothesis
   - Viscous subrange, Inertial subrange, Energy containing range
   - Energy spectrum
   - Structure functions
   - Two-point correlations
   - Intermittency
6. Wall flows
   - Channel flow, pipe flow, boundary layer flows
   - Mean velocity profile
   - Viscous sublayer, buffer layer, logarithmic layer
   - Inner and outer layer
   - Friction law
7. Simulations of turbulent flows
   - We discuss the concepts, benefits, limitations of the most widely used simulation techniques of turbulent flows, i.e.
   - Reynolds Averaged Navier Stokes (RANS)
   - Large-eddy simulations (LES)
   - direct Numerical simulations (DNS)
8. Discussion of special topics in turbulence
   - Theory of heat transfer in turbulent convection
   - Wind farm fluid dynamics

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