Samenvatting SKO project
Erik van Heumen

Professionalisering van de AMEP track

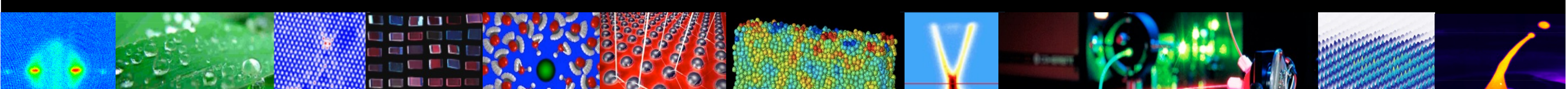
Advanced
Matter
&
Energy
Physics

Erik van Heumen
e.vanheumen@uva.nl

van der Waals - Zeeman institute
Institute of Physics

Part of the joint degree MSc. Program Physics and Astronomy

Th. Phys.	AMEP	AA	GRAPPA	BB	SfES



Inhoudsopgave

Samenvatting

In dit SKO-project heb ik de eerste stappen gezet naar het professionaliseren van de AMEP-track binnen het MSc. Programma Physics & Astronomy.
De opbrengst voor de track zijn nieuwe eindtermen die zullen gaan gelden in collegejaar 2022-2023. Verder is er een begin gemaakt met het in alignment brengen van de vakken met de eindtermen. Aan het eind van het project ben ik begonnen met het opzetten van een werkgroep om het toetsbeleid beter vast te leggen.
In de volgende pagina's vat ik de belangrijkste opbrengsten samen. Eerst volgt een korte motivatie voor dit project.

Introductie: de Advanced Matter & Energy Physics track

De AMEP track is in 2010 ontstaan en sindsdien is er weinig tot geen onderhoud uitgevoerd.De track na 10 jaar toe aan een grondige revisie van het onderwijsprogramma, de doelstellingen en afstemming van de activiteiten met veranderingen in het werkveld. Ten tweede, zoekt 50% van onze studenten na de MSc een baan buiten de wetenschap (dit geldt voor de hele Ph&A opleiding). Op dit moment wordt hier binnen de opleiding onvoldoende rekening mee gehouden.

Dit was voor mij het beginpunt van mijn SKO-traject. Bij aanvang heb ik de volgende doelstellingen geformuleerd:

- Er is behoefte aan het herzien van de beoogde eindtermen, met name ten aanzien van de aansluiting met externe stakeholders. Een belangrijk aandachtspunt hierbij is een betere focus op een carrière buiten de academische wereld.
- De instroom in de track moet vergroot worden.
- De atmosfeer binnen de track en uitstraling naar buiten toe kunnen verder verbeterd worden.
- Het AMEP curriculum heeft behoefte aan kernvakken die gebruik maken van verschillende toetsvormen en waarvan de volgorde in het curriculum is opgebouwd volgens de piramide van Miller.

De piramide van Miller wordt veel bij medische opleidingen gebruikt. Met name de opbouw van niveaus van bekwaamheid en de bijbehorende toetsvormen zijn, naar mijn mening, een goede manier om studenten met zeer verschillende niveaus van basiskennis snel tot hetzelfde niveau te brengen. Daarnaast is het model goed uit te leggen in de context ven een research master en biedt het aanknopingspunten voor het verbeteren van de competenties die een student nodig heeft bij aanvang van het onderzoeksproject.

Naar nieuwe eindtermen

Curriculum aanpassing

De eerste stap in het SKO-project is gezet met het doorvoeren van een aantal veranderingen in het curriculum. Een uitgebreide motivatie, overzicht van het originele programma en het nieuwe programma laat ik hier achterwege, maar is beschikbaar. De belangrijkste toevoegingen aan het programma:

- Programming for AMEP: programmeren in Mathematica en Python.

- AMEP seminars: Organiseren van lunch meetings, outreach activiteiten en web presence.
- Academic skills: Open problems in AMEP en Professional Skills (bestaande uit zes 1.5 EC modules waaronder Effective communication)

Het doel van deze nieuwe vakken is om de '21st century' skills beter in het curriculum te verankeren. De cursus programmeren draagt bij aan het onderzoeksproject in het 2e jaar, maar geeft alle afgestudeerden ook een belangrijke basis voor een carrière waarbij ICT in combinatie met analytische vaardigheden een hoofdrol speelt. De AMEP seminars zijn voornamelijk bedoeld om de studenten een beter overzicht te geven van hun toekomstige werkveld, zowel binnen als /buiten de academie. In de eerste vier periodes van het academisch jaar organiseren de studenten zelf seminars waar docenten, promovendi en externe sprekers (waaronder AMEP alumni) over hun onderzoek of werk vertellen. In de laatste periode wordt een projectenmarkt georganiseerd waar studenten en docenten samen komen en onderhandelen over onderzoeksprojecten voor het tweede studiejaar.

De huidige eindtermen

De eindtermen van de MScPh&A bestaan uit 2 delen: deel 1 betreft algemene vaardigheden en doelen die alle afgestudeerden zouden moeten behalen terwijl deel 2 track specifiek zijn. In bijlage 1 staan de algemene eindtermen van de MSc.Ph&A vermeld.

De eindtermen voor het AMEP specifieke deel in 2021 – 2022 zijn als volgt:

> In addition to paragraph 1 and 2, the student who has completed the track Advanced Matter and Energy Physics has obtained the following track-specific qualifications:
>
> a) a well-founded knowledge of the theoretical background behind experimental physics in the sub-disciplines: (hard and soft) condensed matter physics; atomic and laser physics;
> b) a well-founded knowledge of experimental approaches of relevance in modern research into at least one of the following research fields:
>   i. Emergent materials, strongly correlated electron systems and unconventional superconductivity;
>   ii. Energy materials and processes for (solar) energy conversion;
>   iii. Complex liquids, granular and soft bio-matter and metamaterials;
>   iv. High-precision laser spectroscopy, ultracold quantum gases, quantum information and simulation with ultracold atoms or molecules.
>   v. Computational methods in hard and soft condensed matter.
> c) proficiency in applying the theoretical knowledge learned to enable the interpretation of the results from experimental work - executed by the graduate at least in part as an independent investigator able to do guided research - in a research project in a field within or close to those given in section b above.

Mijn belangrijkste bezwaren tegen deze eindtermen zijn als volgt:

- "Well founded knowledge", "proficiency in…" en soortgelijke kwalificaties zijn niet duidelijk gedefinieerd en moeilijk toetsbaar. Wanneer heeft de student dit in voldoende mate aangetoond en hoe, waar en wanneer wordt dit getoetst?
- Dient de afgestudeerde student bekwaam te zijn in alle sub-disciplines van de track (zoals wordt gesuggereerd in (a)) of slechts in een enkel onderdeel (zoals in (b))?
- De genoemde onderzoeksvelden zijn zeer specifiek en dekken het huidige werk- en onderzoeksveld niet.

De nieuwe eindtermen

In samenwerking met de WZI staf heb ik nieuwe eindtermen geformuleerd tijdens drie staf bijeenkomsten. Deze eindtermen heb ik vervolgens in overleg met Ivo van Stokkum en Jasper van Wezel en een select aantal vakcoördinatoren aangescherpt. Na een aantal rondes van feedback zijn de volgende eindtermen klaar om in de *Teaching & Exam Regulations 2022-2023* opgenomen te worden. De formulering is als volgt:

> In addition to paragraph 1 and 2, the student who has completed the track Advanced Matter and Energy Physics has obtained the following track-specific qualifications:
>
> a. The student has acquired a background in soft and condensed matter and quantum technology, which will enable them to understand current developments in those fields and which is demonstrated by their ability to discuss and apply results of current literature in individual and group projects. The student:
>   i. will be able to explain the relation between macroscopic and microscopic properties of materials and apply this knowledge to nano-scale structures, fluid dynamics, materials with emergent properties or materials for energy applications.
>   ii. will be able to explain the quantum behavior of atoms, electrons and photons in materials, liquids or gasses and is able to apply this knowledge in relation to quantum science and technology.
>   iii. is familiar with light-matter interactions and can apply this knowledge in the context of energy applications, microscopy of soft and biological matter, nano-photonics, nanolithography, or quantum science.
>   iv. Can create simulations, perform computations, and/or experiments to study the equilibrium properties and dynamics of materials, photonic structures, or fluids.
>
> b. The student has demonstrated their ability to deepen their knowledge through self-study in one of the topics i-iv listed under (a) during a research project.
>
> c. In a research setting, the student can compare experimental observations with theoretical frameworks and is able to derive conclusions from this comparison.

Deze eindtermen voldoen aan de volgende eisen:

- Onder de punten a – c is duidelijk wat van de student verwacht wordt en wanneer dit van de student verwacht wordt.
- De punten i-iv omschrijven het soort onderzoek dat binnen de AMEP-track wordt gedaan en beschrijft onderwerpen in meer algemene natuurkundige termen. Daarmee zijn ze minder onderhevig aan veranderingen of hypes.

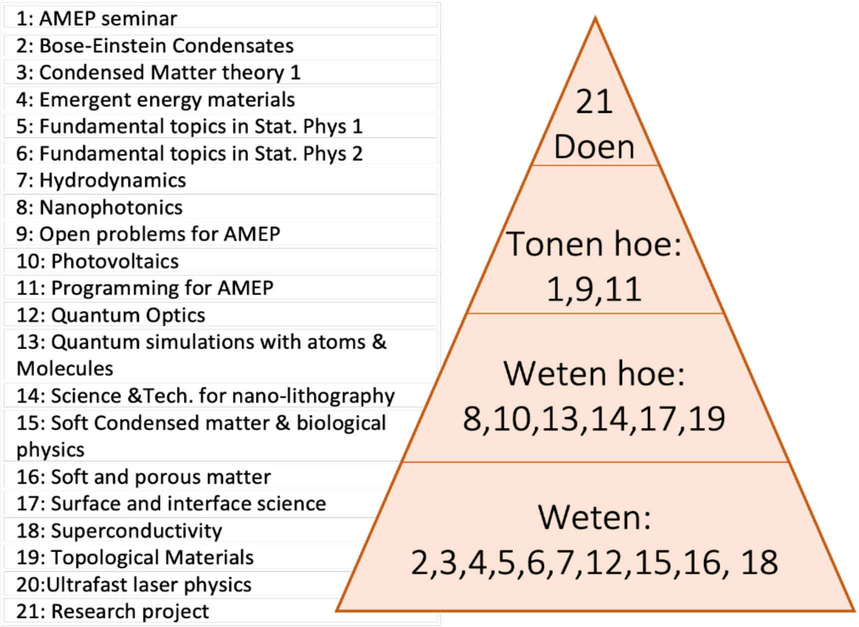
Van eindtermen naar vakleerdoelen

Naast het formuleren van nieuwe eindtermen heb ik in 2021 ook gewerkt aan het formuleren van een overkoepelend leerdoel voor elk vak dat aan AMEP gelieerd is. Een eerste taak was om uit beschikbare informatie een overzicht te maken van de leerdoelen zoals docenten die zelf hadden geformuleerd. Dit overzicht is bijgevoegd als bijlage 2. Met deze informatie in hand heb ik in overleg met de vakcoördinator van elk vak een overkoepelend leerdoel opgesteld. Deze zijn hieronder weergegeven in tabel 2. De laatste kolom geeft een eerste afbeelding van deze leerdoelen op de nieuwe eindtermen.

Tabel 1: overzicht van vakken met bijbehorende leerdoelen. De laatste kolom is een eerste poging leerdoelen aan eindtermen te koppelen.

Course	The student has organized scientific seminars in a professional manner and has contributed to outreach activities related to the AMEP track.	1j, 1k
Bose-Einstein Condensates	The student can explain the basic principles of Bose-Einstein condensates and apply this knowledge to the interpretation of experiments.	aii, aiii
Condensed Matter theory 1	The student can describe the basic principles of the quantum theory of condensed matter physics and can solve problems using low energy effective theories, mean field theory, and/or perturbation theory.	ai, aii
Emergent energy materials	The student can explain the role played by crystal symmetry and nanoscale confinement in determining the properties of emergent and energy materials and is able to apply this knowledge in the study of current literature.	ai, aiii, b
Fundamental topics in Stat. Phys 1	The student is familiar with the fundamental classes of statistics and can distinguish predict when these classes are relevant using simulations or by solving problems in statistical physics.	ai,aiv
Fundamental topics in Stat. Phys 2	The student can explain how simple models can give rise to complex phenomena in both living and non-living systems, and how to analyze such systems when the underlying equations are unknown or uninformative.	ai,aiv
Hydrodynamics	The student can identify different theories describing different types of fluid flows and is able to describe hydrodynamic problems with theoretical and computational methods.	ai,aiv
Nanophotonics	The student understands how nanoscale boundary conditions influence the mode structure of Maxwell's equations and can use this knowledge to design strategies to manipulate light.	aii, aiii, b
Open problems for AMEP	The student can describe the scientific process behind publishing and can evaluate the societal and scientific relevance of published works.	2a,2b
Photovoltaics	The student can explain the basic operating principles of a solar cell and can identify bottlenecks and opportunities in the development of solar cells.	aii, aiii
Programming for AMEP	The student can use Mathematica and python to solve problems or analyze data from different sources.	aiv
Quantum Optics	The student can explain the basic quantum properties of light and is able to apply this knowledge to explain modern experiments and iconic examples.	aii,b
Quantum simulations with atoms & Molecules	The student can apply knowledge of Fermi gasses to predict outcomes of quantum simulations and is familiar with experimental methods to realize these simulations.	aii, aiv
Science &Tech. for nano-lithography	The student can identify and apply physical concepts in relation to nano-lithography and can explain challenges in current developments in this field.	aiii,b
Soft Condensed matter & biological physics	The student can identify building blocks of cells and explain how these contribute to the function of living organisms.	aiii
Soft and porous matter	The student can explain how gases and fluids are transported in confined environment (pore-networks) and are able to relate this to the mechanical behaviour of the material.	aiii
Surface and interface science	The student can explain the concepts of surface structure, surface-specific analysis methods, and the influence of surfaces and interfaces on the physical properties of materials and is able to place this in the context of current literature.	ai,b
Superconductivity	The student can explain and apply basic concepts of superconductivity, identify novel superconductors and communicate applications of superconductors.	ai, aii
Topological Materials	The student can identify and explain topological edge states and topological defects in real and meta-materials and apply this knowledge to a topic taken from the current literature.	ai, b
Ultrafast laser physics	The student can apply the theoretical description of ultrafast laser pulses to experiments and current literature.	aii, b
Research project	The student demonstrates their ability to apply knowledge in a research setting.	b, c

Doelen voor 2022-2023



Figuur 1 :Overzicht van vakken en hun relatie tot de piramide van Miller.

Voor de AMEP track wil ik verder ontwikkelen op het toets beleid. In eerste instantie zal de nadruk liggen op het analyseren van de toetsen die in het curriculum worden gebruikt. Hiervoor heb ik al een eerste versie van een piramide van Miller gemaakt (zie figuur 4). Een geode basis hiervoor is het boek *Toetsen in het hoger onderwijs* van van Berkel[7]. Ook ben ik bij een klein aantal cursussen bezig met het opdoen van ervaring met *specification grading*[11].

Referenties

1. Facultaire Studenten Raad. Stemadvies FSR FNWI aan GV omtrent AFS. (2013).
2. Brouwer, J. & in't Veld, R. Achieving certification and innovation simultaneously: educational leadership for senior faculty at a research university in the Netherlands. in *The Palgrave Handbook of Academic Professional Development Centers* (Springer, 2020).
3. QANU. Accreditatie rapport Joint degree Physics and astronomy (UvA/VU).
4. van Duin, H. Advies Commissie Sectorplan Beta en Techniek.
5. Connecting Science in a Changing World. (2021).
6. Kallenberg, T. *Organiseren en innoveren in het hoger onderwijs*. (Boom Lemma uitgevers).
7. van Berkel, H., Bax, A. & Joosten-ten-Brinke, D. *Toetsen in het hoger onderwijs*. (Bohn Stafleu van Loghum, 2014).
8. Visscher-Voerman, I. & Gustafson, K. L. Paradigms in the theory and practice of education and training design. *ETR&D* **52**, 69–89 (2004).
9. Boele, K. *Onderwijsheid: terug naar waar het echt om gaat*. (Uitgeverij Klement, 2016).
10. Biggs, J. & Tang, C. *Teaching for Quality Learning at University*. (Open University Press, 1999).
11. Nilson, L. *Specifications Grading: Restoring Rigor, Motivating Students, and Saving Faculty Time*. (Stylus Publishing).
12. Fink, L. D. A Self-Directed Guide to Designing Courses for Significant Learning. 37.
13. van den Bos, P. Toetsen om te leren. (2016).

Bijlage 1: general exit qualifications MSc. Physics & Astronomy

Current general exit qualifications from the teaching and exam regulations 2021 -2022.

The graduate of the Master's programme Physics and Astronomy:

a) has a thorough theoretical and practical knowledge of modern physics/astronomy, including the knowledge of other disciplines required for that purpose;
b) has a thorough knowledge of theoretical and/or experimental methods and research experience in at least one sub-area within the physics/astronomy discipline;
c) is able to become acquainted with other sub-areas of the physics/astronomy discipline within a reasonable period of time;
d) is able to formulate a research plan based on a realistic problem definition within the physics/astronomy discipline;
e) is able to analyse and formulate research results and to draw conclusions;
f) is able to write a scientific report or an internationally accessible scientific publication and to participate in discussions on (specialised) topics in the field of study;
g) is able to consult international professional literature in the relevant sub-areas and to apply the knowledge gained from that;
h) is able to apply one's knowledge of physics/astronomy in a broader (multidisciplinary) context;
i) is employable in those positions for which knowledge and research skills in the field of physics/astronomy are a prerequisite;
j) has sufficient knowledge of, and insight in the social role of physics/astronomy to make a sound choice regarding one's own profession, as well as in the exertion of this profession;
k) is able to cooperate with other people, to convey knowledge to other people, and to give a presentation both to discipline specialists and to a broader audience.
l) is familiar with the rules of scientific integrity and is acting accordingly.

Students selecting an experimental or observational master's programme must be able to independently conduct experiments, or devise observations and the corresponding controls, conducting and evaluating these within a given period of time. In addition, each graduate in the programme curriculum:

a) is able to compare and incorporate obtained research results and conclusions within the framework of the results of other scientists;
b) is able to form a vision on the development of scientific research in the field of physics/astronomy;
c) is able to quantitatively and qualitatively analyse physics/astronomy processes, to incorporate data in existing or new models and to present the results at various levels of abstraction.

Bijlage 2: Learning outcomes Advanced Matter & Energy Physics

The learning outcomes of the AMEP curriculum and the learning objectives of individual components of the program are summarized in this document. The AMEP track consists of three pillars focusing on specific areas of physics. Each pillar covers topics ranging from fundamental concepts to applications.

Pillar 1: emergent & energy materials (E&EM) focusses on condensed matter physics and the interaction between light and matter.

Pillar 2: atomic quantum physics (AQP) focusses on fundamentals of model quantum systems.

Pillar 3: soft and bio matter (SBM) focusses on mesoscopic and macroscopic properties of condensed matter and biological systems.

In principle, these pillars are loosely defined study tracks, and we expect students to choose courses that fall within a pillar. Records indicate that most students indeed follow these paths. This makes it important that the courses contained in a pillar have continuous learning objectives, preferably without too much overlap. Of course, it is often very useful to repeat basic concepts in different courses. However, too much overlap in examination of these concepts should be prevented. In addition, some basic concepts should be treated before others in the AMEP course.

General courses

Academic skills

There is a wide range of choices focusing on soft skills. For AMEP we suggest one of the following:

AMEP seminar

After successful completion of this course, you will have learned how to conceive, plan, and carry out the instigation, conception and organisation of regular scientific meetings in a professional academic research setting.

Skills learned include:

- generating a compelling and varied scientific program of content;
- recruiting speakers;
- identifying and responding to opportunities for in- and outreach;
- effective and professional communication about the seminar series via email, web-site, coffee-room flyers, social media
- Conceive, plan, and carry out the instigation, conception and organisation of regular scientific meetings
- Identifying and responding to opportunities for in- and outreach
- *Each AMEP cohort shares the collective objective of generating and securing this central and vibrant part of AMEP-life for the year they are entrusted with*

Programming for AMEP

- The student knows the main differences between Mathematica and procedural programming languages
- The student can use Mathematica for symbolic computation and checking units.
- The student can use Mathematica and Python to import, export and visualize data, as well as graphically explore algebraic expressions.
- The student is familiar with a breadth of numerical analysis, computational and simulation techniques
- The student can use Python to build computational & simulation tools and carry out a variety of computational tasks
- The student can use Python for data analysis and visualization

Learning objectives Pillar 1 (E&EM)

Emergent Energy Materials

- The student can use basic concepts related to the electronic structure of solids.
- The student can use basic concepts related to the mechanical properties of solids.
- The student can use basic concepts related to the thermodynamics of solids.
- The student can explain basic physical and chemical concepts related to the use of nanostructured materials in energy conversion and energy storage applications.
- The student can explain the relation between microscopic degrees of freedom and emergent phenomena in transition metal oxides.
- The student can explain the role of nanoscale confinement in intercalation solids used as electrodes in batteries.
- The student has a working understanding of the relationship between size and optical properties of nanoscale semiconductors (quantum dots).
- The students understands the role and importance of nano-materials in heterogeneous catalysis.
- The student can determine the effect of crystal field splitting in different environments.
- The student can explain the difference between direct exchange, super exchange and double exchange.
- The student can explain the difference between a thermal and quantum phase transition.

Condensed Matter theory 1

- Students will be able to discuss classic results of modern statistical and condensed matter physics.
- Students will learn to apply methods of condensed matter physics.
- Students will learn to recognise concepts of condensed matter physics, and place them in context.

The science and technology of nano-lithography

- the student is able to reproduce and apply new, advanced physics concepts from areas relevant for nanolithography such as advanced optics, plasma physics, surface science, photochemistry, and new concepts in metrology.
- the student is able to apply and combine basic and advanced physic concepts (e.g. also from BSc courses on solid state physics; atomic, molecular and optical physics) to analyze and solve concrete problems that transcend individual physics domains in state-of-the-art nanolithography, specifically in the nanolithography fields of: Optics for extreme ultraviolet light; Laser-driven plasma light sources; Optical inspection and metrology; Thin films and surfaces and their interactions with light
- the scientific challenges and fundamental limits facing physicists performing research in the field of nano-lithography

Photovoltaics

- be able to describe how the photovoltaic cell works and understand the physical processes determining its spectral response, internal and external efficiency and limitations.
- be able to show and explain the limiting factors and bottleneck of photovoltaics
- be aware of (some) of the prominent research avenues towards highly efficient (nano)photovoltaics of next generation.

Topological Materials

- The student is able to identify fingerprints of topological edge states and topological defects in quantum materials, magnetic materials, soft matter and metamaterials.
- The student is able to explain what topological invariants are.
- The student can calculate Chern numbers.
- The student is able to demonstrate the presence of topological edge states.
- The student is able to explain the role played by time reversal symmetry in fermionic and bosonic topological materials.
- The student is able to explain what topological defects are.
- The student can calculate the critical temperatures of a Berezhinski Kosterlitz Thouless phase transition.
- The student can derive the shape of topological solitons and calculate their topological charge.
- The student can identify topological defects in a given field configuration.

Superconductivity

- Comprehend and apply basic concepts of superconductors and to derive and apply the London equations.
- Apply the Ginzburg-Landau equations to the superconducting phase transition and to extend these to inhomogeneous superconductors and in magnetic field.
- Formulate, understand and apply the basic concepts of the microscopic theory of superconductivity: the BCS theory.
- Understand and apply the concepts of unconventional superconductivity.

- Derive and apply the Josephson equations and their extension to a magnetic field in simple and more complicated situations, such as SQUID operation.
- Identify novel and classical superconductors, and understand and communicate the applications of superconductivity.

Nanophotonics

- Explain what the field of nanophotonics is, including all the subthemes listed under course content, and how it is applicable to novel light sources, detectors, optical information processing, photovoltaics and quantum optics.
- To analyze classical electrodynamics problems involving the physical optics of diffraction, scattering, interference and pulse propagation in complex metallic, dielectric, and periodic systems, showing their direct relevance in actual photonic structures.
- Presentations of high-impact nanophotonics papers will further strengthen the process of gaining 'mastery' of this material, so that the student is able to critically discuss current developments in nanophootonics, and compare them to the state of the art.

Learning objectives Pillar 2 (AQP)

Quantum optics

- Can explain the characteristic features of atom-light interaction in the semiclassical approximation, both qualitatively and quantitatively; can name the key quantities and can explain how they are connected.
- Can describe the similarities and differences between the semiclassical and fully quantized descriptions of atom-light interaction, can write down a prototypical full quantum Hamiltonian.
- Is familiar with the concept of ‘coherence’ and understands how it is related to interference.
- Can describe the formal description of light fields in quantum optics, can explain the concepts ‘mode’ and ‘photon’, knows several well-known quantum states of quantized modes and can calculate their elementary properties.
- Masters the algebra of photon creation and annihilation operators and can use this to calculate photon statistics for some illustrative examples.
- Can explain the role of quantum optical concepts in a selection of modern experiments.
- Can describe the basic principles and concepts of quantum information, including qubits, coherence, entanglement and quantum gates; can name some of the experimental issues and efforts to implement these ideas.

Bose Einstein Condensates

- The student will know the basic building blocks of an ultracold quantum gas machine and how these building blocks interact to create and study BECs.
- The student will learn and apply the theory of Bose quantum gases
- Exp#1: Overview of ultracold quant gases: What? Why? How?
- Exp#2: Atom-laser interaction, Bloch sphere

- Exp#3: Dressed state picture, Optical Bloch equations, Detecting an ultracold gas
- Exp #4: Light forces, Molasses cooling, Sisyphus cooling
- Exp#5: Atomic beam oven, Zeeman slower, Magneto-optical trap, Technology for laser cooling
- Exp#6: Optical dipole trap, Magnetic trap, Trap technology, Evaporative cooling, Characterizing a BEC
- Exp#7:Characterizing a BEC
- Th#1:Ultracold atomic gases. Interaction between particles. Elastic and inelastic interatomic collisions.
- Th#2:Bose-Einstein condensation in an ideal gas. Crucial role of the density of states.
- Th#3:Interacting Bose-Einstein condensates. Gross-Pitaevskii equation. Stable and collapsing condensates in an external harmonic potential.
- Th#4:Dynamics of Bose-Einstein condensates. Expanding and oscillating condensates.
- Th#5:Elementary excitations. Bogoliubov-De Gennes equations. Density-phase representation.
- Th#6:Bose-Einstein condensates at finite temperatures. Thermal and quantum fluctuations. Damping of excitations.
- Th#7:Two-dimensional Bose gases. Kosterlitz-Thouless transition. True and quasi condensates.
- Th#8:Quantum vortices in Bose-condensed gases. Vortex lattice and Tkachenko modes.
- Th#9:True and quasi condensates in one-dimensional trapped gases.
- Th#10:Solitons in 1D Bose-condensed gases.
- Th#11:Strongly interacting 1D Bose gases. Impenetrable bosons.
- Th#12:Rapidly rotating Bose gases. Mean field regime and strongly correlated Quantum Hall states.

Ultrafast laser physics

- To understand contemporary literature (e.g. research papers) on ultrafast lasers and their many (amazing) applications, ranging from attosecond physics to ultra-precise measurements for tests of the fundamental laws of physics
- Understand the theoretical and practical aspects of experiments with ultrafast laser pulses.

Quantum simulations with atoms and molecules

- Introduction: Quantum simulation
- Fermi gases: Creation and detection; Interaction tuning: Feshbach resonances; BEC-BCS crossover: what is it? Measuring the pairing gap; The unitary Fermi gas: equation of state, second sound; Polarons.
- Bose-Hubbard model: lattices, Bloch- and Wannier functions, optical lattices, Bose-Hubbard model (outline of derivation), approximations, intuitive undertstanding of superfluid to Mott insulator transition, phase-diagram derived using Gutzwiller Ansatz, experimental implementation, detection of phase transition in momentum space, quantum gas microscopy, detection in real space

- Magnetism: Origin of magnetism in solid state, types of exchange interaction; Observation of super-exchange interaction; Quantum dynamics of spin impurity observed with quantum gas microscope; Quantum simulation of antiferromagnetic spin chains; Changing the tunnel matrix element by shaking; Quantum simulation of frustrated classical magnetism in triangular optical lattice.
- Techniques in ion trapping: Paul and Penning traps, ion cooling and detection
- Spin-spin interactions and quantum gates: Collective modes of ion motion, qubits, mediated interactions, quantum simulation and computation with trapped ions.

Learning objectives Pillar 3 (SBM)

Fundamental topics in Stat. Phys 1

- Students will become familiar with a the most commonly encountered classes of statistical problems
- Students will know how to construct and motivate scaling arguments
- Students will be able to set up simple numerical simulations
- Students will know how to perform data analysis on simulational data
- Students will be able to apply mathematical tools to study statistical problems

Fundamental topics in Stat. Phys 2

- Understand and apply various concepts and tools of statistical physics, dynamical systems and information theory to problems in complex systems, especially those arising in living matter.
- Understand how complex phenomena can arise even from simple theoretical descriptions, and how this influences the scientific methodology of our investigation.
- Understand the interplay between theoretical ideas and data derived from precision experiments, including computational experiments. Leverage this understanding to derive new knowledge of complex systems.

Soft condensed matter & biological physics

- To provide insight into the physics of biological systems and soft condensed matter.

Hydrodynamics

- The student gets acquainted with the physical theories that give a quantitative description of flows, notably: Microfluidics; Governing; Equations for flows; Basic Flow Solutions; Hydraulics; Diffusion; Time-dependent flows; Capillary effects; Electrohydrodynamics, Electro-osmosis, Electro- and Magnetophoresis
- the student will be able to analyze new research results
- the student will be able to quantitatively describe a large number of commonly encountered hydrodynamic phenomena.
- Computational Fluid Dynamics (CFD) techniques will be introduced to solve hydrodynamics problems where the basic analytical methods do not suffice.

Soft and porous matter

- The student will understand the mechanisms involved in transport processes in porous media and will be able to work with the equations that govern the fate and transport of gas, water and solutes in porous media
- The student will learn how the self assembly of soft molecules such as surfactants and gels influence the micro structure of the resulting materials and their properties.
- The student will be able to express and translate hydrodynamics for a better understanding of the dynamics of transport and fluid flow in such materials
- The student will be able to solve basic mechanical problems in advanced elasticity. E.g. they will be able to predict how elastomers and hydrogels respond under mechanical or osmotic load.
- The student will be able to identify and theoretically predict dramatic events in soft and porous media such as instabilities and fracture

Surface and interface science

- A basic knowledge of Surface and Interface physics and chemistry plus typical experimental techniques in these fields.
- Identify key items in research articles on surface science and present them to other students
- Describe the key items in research articles on surface science and answer questions about them in an essay
- Solve homework problems related to the contents of the lecture