Elective Advanced Lectures: Experimental Physics - physics70a

Module No.	**physics70a**
Category	Elective
Credit Points (CP)	3-6
Semester	1.-2.

Module: Elective Advanced Lectures: Experimental Physics

Module Elements:

Nr	Course	Course No.	CP	Type	Teaching hours	Semester
1	Particle Astrophysics and Cosmology (E)	physics711	6	Lect. + ex.	3+1	WT
2	Advanced Electronics and Signal Processing (E/A)	physics712	6	Lect. + ex.	3+1	ST
3	Particle Detectors and Instrumentation (E/A)	physics713	6	Lect. + lab.	3+1	ST
4	Advanced Accelerator Physics (E/A)	physics714	6	Lect. + ex.	3+1	ST/WT
5	Experiments on the Structure of Hadrons (E)	physics715	4	Lect. + ex.	2+1	WT
6	Statistical Methods of Data Analysis (E)	physics716	4	Lect. + ex.	2+1	ST
7	High Energy Physics Lab (E)	physics717	4	Laboratory		WT/ST
8	Programming in Physics and Astronomy with C++ or Python (E/A)	physics718	4	Lect. + ex.	2+1	ST
9	Intensive Week: Advanced Topics in High Energy Physics (E)	physics719	3		2	WT/ST
10	Physics with Antiprotons (E)	physics720	3	Lecture	2	WT
11	Intensive Week: Advanced Topics in Hadron Physics (E)	physics721	4		3	WT/ST
12	Advanced Gaseous Detectors - Theory and Practice (E)	physics722	6		3+1	ST
13	Hands-on Seminar: Detector Construction (E/A)	physics723	3		2	WT/ST
14	Advanced Methods of Data Analysis (E)	physics724	4	Lect. + ex.	2+1	WT/ST
15	Low Temperature Physics (E/A)	physics731	6	Lect. + ex.	3+1	WT/ST
16	Optics Lab (E/A)	physics732	4	Laboratory		WT/ST
17	Holography (E/A)	physics734	3	Lecture	2	ST
18	Laser Cooling and Matter Waves (E)	physics735	3	Lecture	2	WT/ST
19	Crystal Optics (E/A)	physics736	6	Lect. + ex.	3+1	WT
20	Intensive Week: Advanced Topics in Photonics and Quantum Optics (E)	physics737	4	Lect. + lab. + sem.	3	WT/ST
21	Lecture on Advanced Topics in Quantum Optics (E)	physics738	4	Lect. + ex.	2+1	WT/ST
22	Lecture on Advanced Topics in Photonics (E/A)	physics739	4		2+1	WT/ST

Nr	Course	Course No.	CP	Type	Teaching hours	Semester
23	Hands-on Seminar: Experimental Optics and Atomic Physics (E/A)	physics740	3		2	WT/ST
24	Modern Spectroscopy (E/A)	physics741	4		2+1	WT/ST
25	Ultracold Atomic Gases (E/T)	physics742	6	Lect. + ex.	3+1	WT
26	Platforms for Quantum Technologies (E)	physics743	5	Lect. + ex.	2 weeks fulltime	WT/ST
27	Internships in the Research Groups	physics799	4	internship		WT/ST

Requirements for Participation: none

Form of Examination: see with the course

Content: Advanced lectures in experimental physics

Aims/Skills: Preparation for Master's Thesis work; broadening of scientific knowledge

Course achievement/Criteria for awarding cp's: see with the course

Length of Module: 1 or 2 semester

Maximum Number of Participants: ca. 100

Registration Procedure: s. https://basis.uni-bonn.de u. http://bamawww.physik.uni-bonn.de

Note: Note: The student must achieve at least 18 CP out of all 4 Elective Advanced Modules

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Particle Astrophysics and Cosmology (E) - physics711

Course	**Particle Astrophysics and Cosmology (E)**
Course No.	physics711

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	WT

Requirements for Participation:

Preparation: physics611 (Particle Physics), useful: Lectures Observational Astronomy

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Basics of particle astrophysics and cosmology

Contents of the Course:

Observational Overview (distribution of galaxies, redshift, Hubble expansion, CMB, cosmic distance latter, comoving distance, cosmic time, comoving distance and redshift, angular size and luminosity distance); Standard Cosmology (cosmological principle, expansion scale factor, curved space-time, horizons, Friedmann-Equations, cosmological constant, cosmic sum rule, present problems); Particle Physics relevant to cosmology (Fundamental Particles and their Interactions, quantum field theory and Lagrange formalism, Gauge Symmetry, spontaneous symmetry breaking and Higgs mechanism, parameters of the Standard Model, Running Coupling Constants, CP Violation and Baryon Asymmetry, Neutrinos); Thermodynamics in the Universe (Equilibrium Thermodynamics and freeze out, First Law and Entropy, Quantum Statistics, neutrino decoupling, reheating, photon decoupling); Nucleosynthesis (Helium abundance, Fusion processes, photon/baryon ratio)

Dark Matter (Galaxy Rotation Curves, Clusters of Galaxies, Hot gas, Gravitational lensing, problems with Cold Dark Matter Models, Dark Matter Candidates); Inflation and Quintessence; Cosmic Microwave Background (origin, intensity spectrum, CMB anisotropies, Temperature correlations, power spectrum, cosmic variance, density and temperature fluctuations, causality and changing horizons, long and short wavelength modes, interpretation of the power spectrum)

Recommended Literature:

A. Liddle; An Introduction to Modern Cosmology (Wiley & Sons 2. Ed. 2003)

E. Kolb, M. Turner; The Early Universe (Addison Wesley 1990)

J. Peacock; Cosmological Physics (Cambridge University Press 1999)

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Advanced Electronics and Signal Processing (E/A) - physics712

Course	**Advanced Electronics and Signal Processing (E/A)**
Course No.	physics712

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	ST

Requirements for Participation:

Preparation:

Electronics laboratory of the B.Sc. in physics programme

Recommended: module nuclear and particle physics of the B.Sc. programme

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Comprehension of the basics of electronics circuits for the processing of (detector) signals, mediation of the basics of experimental techniques regarding electronics and micro electronics as well as signal processing

Contents of the Course: The physics of electronic devices, junctions, transistors (BJT and FET), standard analog and digital circuits, amplifiers, elements of CMOS technologies, signal processing, ADC, DAC, noise sources and noise filtering, coupling of electronics to sensors/detectors, elements of chip design, VLSI electronics, readout techniques for detectors

Recommended Literature:

P. Horowitz, W. Hill; The Art of Electronics (Cambridge University Press 2. Aufl. 1989)

S. Sze; The Physics of Semiconductor Devices (Wiley & Sons 1981)

H. Spieler, Semiconductor detector system (Oxford University Press 2005))

J. Krenz; Electronics Concepts (Cambridge University Press 2000)

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Particle Detectors and Instrumentation (E/A) - physics713

Course	**Particle Detectors and Instrumentation (E/A)**
Course No.	physics713

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with laboratory	English	3+1	6	ST

Requirements for Participation:

Preparation: Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear physics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Designing an experiment in photoproduction on pi-0, selection and building of appropriate detectors, set-up and implementation of an experiment at ELSA

Contents of the Course: Quark structure of mesons and baryons, nucleon excitation; electromagnetic probes, electron accelerators, photon beams, relativistic kinematics interaction of radiation with matter, detectors for photons, leptons and hadrons; laboratory course: setup of detectors and experiment at ELSA

Recommended Literature:

B. Povh, K. Rith, C. Scholz, F. Zetsche; Teilchen und Kerne (Springer, Heidelberg 6. Aufl. 2004)

Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)

W. R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2. Ed. 1994)

K. Kleinknecht; Detektoren für Teilchenstrahlung (Teubner, Wiesbaden 4. überarb. Aufl. 2005)

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Advanced Accelerator Physics (E/A) - physics714

Course	**Advanced Accelerator Physics (E/A)**
Course No.	physics714

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	ST/WT

Requirements for Participation:

Preparation: Accelerator Physics (physics612)

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course:

Understanding of the physics of synchrotron radiation and its influence on beam parameters

Basic knowledge of collective phenomena in particle accelerators

General knowledge of applications of particle accelerators (research, medicine, energy management)

Contents of the Course:

Synchrotron radiation:

radiation power, spatial distribution, spectrum, damping, equilibrium beam emittance, beam lifetime

Space-charge effects:

self-field and wall effects, beam-beam effects, space charge dominated beam transport, neutralization of beams by ionization of the residual gas

Collective phenomena:

wake fields, wake functions and coupling impedances, spectra of a stationary and oscillating bunches, bunch interaction with an impedance, Robinson instability

Applications of particle accelerators:

medical accelerators, neutrino facilities, free electron lasers, nuclear waste transmutation, etc.

Recommended Literature:

F. Hinterberger; Physik der Teilchenbeschleuniger und Ionenoptik (Springer, Heidelberg 1997)

H. Wiedemann; Particle Accelerator Physics (Springer, Heidelberg 2 Aufl. 1999)

K. Wille; Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen (Teubner, Wiesbaden 2. Aufl. 1996)

D. A. Edwards, M.J. Syphers; An Introduction to the Physics of High Energy Accelerators (Wiley & Sons 1993)

A. Chao; Physics of Collective Beam Instabilities in High Energy Accelerators (Wiley & Sons 1993)

Script of the Lecture Particle Accelerators (physics612)

http://www-elsa.physik.uni-bonn.de/~hillert/Beschleunigerphysik/

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Experiments on the Structure of Hadrons (E) - physics715

Course	**Experiments on the Structure of Hadrons (E)**
Course No.	physics715

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

Requirements for Participation:

Preparation: Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear physics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Understanding the structure of the nucleon, understanding experiments on baryon-spectroscopy, methods of identifying resonance contributions, introduction into current issues in meson-photoproduction

Contents of the Course: Discoveries in hadron physics, quarks, asymptotic freedom and confinement; multiplets, symmetries, mass generation; quark models, baryon spectroscopy, formation and decay of resonances, meson photoproduction; hadronic molecules and exotic states

Recommended Literature:

Perkins, Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)

K. Gottfried, F. Weisskopf; Concepts of Particle Physics (Oxford University Press 1986)

A. Thomas, W. Weise, The Structure of the Nucleon (Wiley-VCH, Weinheim, 2001)

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Statistical Methods of Data Analysis (E) - physics716

Course	**Statistical Methods of Data Analysis (E)**
Course No.	physics716

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

Requirements for Participation:

Preparation:

Form of Testing and Examination: Requirements for the examination (written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Provide a foundation in statistical methods and give some concrete examples of how the methods are applied to data analysis in particle physics experiments

Contents of the Course: Fundamental concepts of statistics, probability distributions, Monte Carlo methods, fitting of data, statistical and systematic errors, error propagation, upper limits, hypothesis testing, unfolding

Recommended Literature:

R. Barlow: A Guide to the Use of Statistical Methods in the Physical Sciences; J. Wiley Ltd. Wichester 1993

S. Brandt: Datenanalyse (Spektrum Akademischer Verlag, Heidelberg 4. Aufl. 1999)

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High Energy Physics Lab (E) - physics717

Course	**High Energy Physics Lab (E)**
Course No.	physics717

Category	Type	Language	Teaching hours	CP	Semester
Elective	Laboratory	English		4	WT/ST

Requirements for Participation:

Preparation: Recommended: B.Sc. in physics, physics611 (Particle Physics) or physics618 (Physics of Particle Detectors)

Form of Testing and Examination: Credit points can be obtained after completion of a written report or, alternatively, a presentation in a meeting of the research group.

Length of Course: 4-6 weeks

Aims of the Course: This is a research internship in one of the high energy physics research groups which prepare and carry out experiments at external accelerators. The students deepen their understanding of particle and/or detector physics by conducting their own small research project as a part-time member of one of the research groups. The students learn methods of scientific research in particle physics data analysis, in detector development for future colliders or in biomedical imaging (X-FEL) and present their work at the end of the project in a group meeting.

Contents of the Course:

Several different topics are offered among which the students can choose. Available projects can be found at http://heplab.physik.uni-bonn.de. For example:

- Analysis of data from one of the large high energy physics experiments (ATLAS, DØ, ZEUS)
- Investigation of low-noise semiconductor detectors using cosmic rays, laser beams or X-ray tubes
- Study of particle physics processes using simulated events
- Signal extraction and data mining with advanced statistical methods (likelihoods, neural nets or boosted

decision trees)

Recommended Literature: Will be provided by the supervisor

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Programming in Physics and Astronomy with C++ or Python (E/A) - physics718

Course	**Programming in Physics and Astronomy with C++ or Python (E/A)**
Course No.	physics718

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

Requirements for Participation:

Preparation: Basic knowledge of programming and knowledge of simple C/C++ or Python constructs.

Form of Testing and Examination:

C/C++ part: Requirements for the examination (written or oral): successful work with the exercises.

Python part: Requirements for examination: successful implementation of the scientific projects in Python during the semester.

Length of Course: 1 semester

Aims of the Course:

C++ part: In-depth understanding of C++ and its applications in particle physics. Discussion of advanced features of C++ using examples from High Energy Physics. The course is intended for students with some background in C++ or for advanced students who wish to apply C++ in their graduate research.

Python part: Effective and flexible program solving with the easy-to-learn, high level programming language Python. The course addresses master and PhD students with prior Python-programming knowledge as taught in the bachelor course physics131.

Contents of the Course:

C++ part: - Basic ingredients of C++, - Object orientation: classes, inheritance, polymorphism, - How to solve physics problems with C++, - Standard Template Library, - C++ in data analysis, example: the ROOT library, - C++ and large scale calculations, - How to write and maintain complex programs, - Parallel computing and the Grid, - Debugging and profiling

Python part: - In-depth introduction to Python based on prior programming experience, - Introduction to numpy arrays (primary Python data structure for scientific computing), - Introduction to scientific-Python modules (scipy, astropy), - Interactive work / development with Python (ipython), - Web interaction with Python (jupyter notebooks, web and database queries), - Plotting with Python (the matplotlib module)

Recommended Literature:

Eckel: Thinking in C++, Prentice Hall 2000.

Lippman, Lajoie, Moo: C++ Primer, Addison-Wesley 2000.

Deitel and Deitel, C++ how to program, Prentice Hall 2007.

Stroustrup, The C++ Programming Language, Addison-Wesley 2000.

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Intensive Week: Advanced Topics in High Energy Physics (E) - physics719

Course	**Intensive Week: Advanced Topics in High Energy Physics (E)**
Course No.	physics719

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Combined lecture, seminar, lab course	English	2	3	WT/ST

Requirements for Participation:

Preparation: Fundamentals of particle physics

Form of Testing and Examination: Seminar talk

Length of Course: 1 - 2 weeks

Aims of the Course: This course is about an advanced, current topic in particle physics. The students will gain insights into recent developments in particle physics and participate in lectures, seminars talks and laboratory projects.

Contents of the Course: As announced in the course catalogue. The main topic will vary from semester to semester.

Recommended Literature: Will be given in the lecture.

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Physics with Antiprotons (E) - physics720

Course	**Physics with Antiprotons (E)**
Course No.	physics720

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture	English	2	3	WT

Requirements for Participation:

Preparation: Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear physics

Form of Testing and Examination: Written or oral examination

Length of Course: 1 semester

Aims of the Course: Insight in current research topics with antiprotons, understanding experimental methods in particle and nuclear physics, understanding interrelations between different fields of physics such as hadron physics, (astro-)particle physics, atomic physics

Contents of the Course: Matter-antimatter asymmetry, test of the standard model, anti-hydrogen, anti-protonic atoms, antiproton beams, key issues in hadron physics with antiprotons, planned research facilities (FAIR) and experiments (PANDA)

Recommended Literature:

B. Povh, K. Rith, C. Scholz, F. Zetsche; Teilchen und Kerne (Springer, Heidelberg 8. Aufl. 2009)

D.H. Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)

further literature will be given in the lecture

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Intensive Week: Advanced Topics in Hadron Physics (E) - physics721

Course	**Intensive Week: Advanced Topics in Hadron Physics (E)**
Course No.	physics721

Category	Type	Language	Teaching hours	CP	Semester
Elective	Combined lecture, seminar, lab course	English	3	4	WT/ST

Requirements for Participation:

Preparation: Fundamentals of hadron physics

Form of Testing and Examination: Presentation, working group participation

Length of Course: 1 - 2 weeks

Aims of the Course: This course will convey recent topics in hadron physics. Guided by lectures, original publications and tutors, the students will prepare a proposal for a planned or recent experiment. The class will not only focus on the experimental aspects, but also on the theoretical motivation for the experiment.

Contents of the Course: As announced in the course catalogue. The main topics will vary from semester to semester.

Recommended Literature: Will be given in the lecture

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Advanced Gaseous Detectors - Theory and Practice (E) - physics722

Course	**Advanced Gaseous Detectors - Theory and Practice (E)**
Course No.	physics722

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with laboratory	English	3+1	6	ST

Requirements for Participation:

Preparation: Completed B.Sc. in physics, with experience in electrodynamics, quantum mechanics, nuclear and particle physics, physics618 (Physics of Particle Detectors)

Form of Testing and Examination: Requirements for the examination (written or oral): submission of report

Length of Course: 1 semester

Aims of the Course:

- Design, construction, commissioning and characterization of a modern gaseous particle detector
- Simulations: GARFIELD, GEANT, FE-Methods, etc.
- Signals, Readout electronics and Data Acquisition
- Data analysis: pattern recognition methods, track fitting
- Scientific writing: report

Contents of the Course:

- Signal formation in detectors
- Microscopic processes in gaseous detectors
- Readout electronics
- Tools for detector design and simulation
- Performance criteria
- Laboratory course: commissioning of detector with sources, beam test at accelerator
- Track reconstruction

Recommended Literature:

http://root.cern.ch

http://garfieldpp.web.cern.ch/garfieldpp/

Blum, Rolandi, Riegler: Particle Detection with Drift Chambers

Spieler: Semiconductor Detector Systems

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Hands-on Seminar: Detector Construction (E/A) - physics723

Course	**Hands-on Seminar: Detector Construction (E/A)**
Course No.	physics723

Category	Type	Language	Teaching hours	CP	Semester
Elective	Laboratory	English	2	3	WT/ST

Requirements for Participation: Basic knowledge of particle physics

Preparation: physics618 is helpful but not mandatory

Form of Testing and Examination: Credit points can be obtained after successful construction and operation of the detector and preparing a written and/or oral report on a specific task

Length of Course: 1 semester

Aims of the Course: Students will design, construct, assemble and operate a particle detector.

Contents of the Course:

Students will construct, assemble and commission a particle detector. They will gain hands-on experience on detector construction. The students organize and execute the tasks of the project in personal responsibility. This includes many tasks common to more complex research or industrial projects. Topics include:

- order the needed detector components
- prepare CAD drawings
- prepare PCB layout
- develop electronic circuits
- produce and assemble detector parts
- vacuum technology
- cooling technology
- organize the work effort in personal responsibility
- communicate with team members and technical staff

Recommended Literature:

H. Kolanoski, N. Wermes, Teilchendetektoren, (Springer, Heidelberg, 2016)

W. R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2. Ed. 1994)

K. Kleinknecht; Detektoren für Teilchenstrahlung (Teubner, Wiesbaden 4. überarb. Aufl. 2005)

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Advanced Methods of Data Analysis (E) - physics724

Course	**Advanced Methods of Data Analysis (E)**
Course No.	physics724

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT/ST

Requirements for Participation: The course builds on the knowledge taught in physics716 Statistical Methods of Data Analysis and is designed as a follow-up course. Participants need to have a working knowledge of the basics of statistical data analysis, including parameter estimation and statistical tests.

Preparation: Students should have a basic knowledge of either C++ or python programming languages. There will be opportunity during the course to develop programming skills through applications of data analysis.

Form of Testing and Examination: The examination can be done either through a written exam or by written term papers as communicated at the beginning of the course.

Length of Course: 1 semester

Aims of the Course: This course teaches advanced techniques of statistical data analysis. Its goal is to enable the participants to contribute to state of the art data analysis projects, for example during their master thesis, and to enable them to conduct their own research into statistical data analysis methods.

Contents of the Course:

Parametric likelihood fits, constraint optimisation, state space models, non-parametric density estimation, unfolding, model validation, introduction to machine learning, classification, adaptive basis function models, ensemble learning, deep generative models

Examples from high energy and hadronic physics.

Recommended Literature:

Elements of statistical learning, 2nd Edition, Hastie, Tibshirani & Friedman, Springer 2017

Data Analysis in High Energy Physics, Behnke et Al. , Wiley-VCH 2013

Statistical Analysis Techniques in Particle Physics, Narsky & Porter, Wiley-VCH 2013

Machine Learning, A Probabilistic Perspective, Murphy, MIT Press 2012

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Low Temperature Physics (E/A) - physics731

Course	**Low Temperature Physics (E/A)**
Course No.	physics731

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	WT/ST

Requirements for Participation:

Preparation: Elementary thermodynamics; principles of quantum mechanics; introductory lecture on solid state physics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Experimental methods at low (down to micro Kelvin) temperatures; methods of refrigeration; thermometry; solid state physics at low temperatures

Contents of the Course: Thermodynamics of different refrigeration processes, liquefaction of gases; methods to reach low (< 1 Kelvin) temperatures: evaporation cooling, He-3-He-4 dilution cooling, Pomeranchuk effect, adiabatic demagnetisation of atoms and nuclei; thermometry at low temperatures (e.g. helium, magnetic thermometry, noise thermometry, thermometry using radioactive nuclei); principles for the construction of cryostats for low temperatures

Recommended Literature:

O.V. Lounasmaa; Experimental Principles and Methods Below 1K (Academic Press, London 1974)

R.C. Richardson, E.N. Smith; Experimental Techniques in Condensed Matter Physics at Low Temperatures (Addison-Wesley 1988)

F. Pobell, Matter and Methods at Low Temperatures (Springer-Verlag, Heidelberg 2. Aufl. 1996)

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Optics Lab (E/A) - physics732

Course	**Optics Lab (E/A)**
Course No.	physics732

Category	Type	Language	Teaching hours	CP	Semester
Elective	Laboratory	English		4	WT/ST

Requirements for Participation:

Preparation:

Form of Testing and Examination: Credit points can be obtained after completion of a written report.

Length of Course: 4-6 weeks

Aims of the Course:

The student learns to handle his/her own research project within one of the optics groups

Available projects and contact information can be found at: http://www.iap.uni-bonn.de/opticslab/

Contents of the Course:

Practical training/internship in a research group, which can have several aspects:

- setting up a small experiment
- testing and understanding the limits of experimental components
- simulating experimental situations

Recommended Literature: Will be given by the supervisor

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Holography (E/A) - physics734

Course	**Holography (E/A)**
Course No.	physics734

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	ST

Requirements for Participation:

Preparation:

Form of Testing and Examination: Written or oral examination

Length of Course: 1 semester

Aims of the Course: The goal of the course is to provide in-depth knowledge and to provide practical abilities in the field of holography as an actual topic of applied optics

Contents of the Course: The course will cover the basic principle of holography, holographic recording materials, and applications of holography. In the first part the idea behind holography will be explained and different hologram types will be discussed (transmission and reflection holograms; thin and thick holograms; amplitude and phase holograms; white-light holograms; computer-generated holograms; printed holograms). A key issue is the holographic recording material, and several material classes will be introduced in the course (photographic emulsions; photochromic materials; photo-polymerization; photo-addressable polymers; photorefractive crystals; photosensitive inorganic glasses). In the third section several fascinating applications of holography will be discussed (art; security-features on credit cards, banknotes, and passports; laser technology; data storage; image processing; filters and switches for optical telecommunication networks; novelty filters; phase conjugation ["time machine"]; femtosecond holography; space-time conversion). Interested students can also participate in practical training. An experimental setup to fabricate own holograms is available

Recommended Literature:

Lecture notes;

P. Hariharan; Optical Holography - Principles, Techniques, and Applications (Cambridge University Press, 2nd Edition, 1996)

P. Hariharan; Basics of Holography (Cambridge University Press 2002)

J. W. Goodman; Introduction to Fourier Optics (McGraw-Hill Education - Europe 2nd Ed. 2000)

A. Yariv; Photonics (Oxford University Press 6th Ed. 2006)

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Laser Cooling and Matter Waves (E) - physics735

Course	**Laser Cooling and Matter Waves (E)**
Course No.	physics735

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT/ST

Requirements for Participation:

Preparation: Basic thermodynamics: fundamentals of quantum mechanics, fundamentals of solid state physics

Form of Testing and Examination: Written or oral examination

Length of Course: 1 semester

Aims of the Course: The in-depth lecture shows, in theory and experiments, the fundamentals of laser cooling. The application of laser cooling in atom optics, in particular for the preparation of atomic matter waves, is shown. New results in research with degenerated quantum gases enable us to gain insight into atomic many particle physics

Contents of the Course: Outline: Light-matter interaction; mechanic effects of light; Doppler cooling; polarization gradient cooling, magneto-optical traps; optical molasses; cold atomic gases; atom interferometry; Bose-Einstein condensation of atoms; atom lasers; Mott insulator phase transitions; mixtures of quantum gases; fermionic degenerate gases

Recommended Literature: P. v. d. Straten, H. Metcalf; Laser Cooling (Springer, Heidelberg 1999)

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Crystal Optics (E/A) - physics736

Course	**Crystal Optics (E/A)**
Course No.	physics736

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+1	6	WT

Requirements for Participation:

Preparation:

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: Because of their aesthetic nature crystals are termed "flowers of mineral kingdom". The aesthetic aspect is closely related to the symmetry of the crystals which in turn determines their optical properties. It is the purpose of this course to stimulate the understanding of these relations. The mathematical and tools for describing symmetry and an introduction to polarization optics will be given before the optical properties following from crystal symmetry are discussed. Particular emphasis will be put on the magneto-optical properties of crystals in magnetic internal or external fields. Advanced topics such as the determination of magnetic structures and interactions by nonlinear magneto-optics will conclude the course

Contents of the Course: Crystal classes and their symmetry; basic group theory; polarized light; optical properties in the absence of fields; electro-optical properties; magneto-optical properties: Faraday effect, Kerr effect, magneto-optical materials and devices, semiconductor magneto-optics, time-resolved magneto-optics, nonlinear magneto-optics

Recommended Literature:

R. R. Birss, Symmetry and Magnetism, North-Holland (1966)

R. E. Newnham: Properties of Materials: Anisotropy, Symmetry, Structure, Oxford University (2005)

A. K. Zvezdin, V. A. Kotov: Modern Magnetooptics & Magnetooptical Materials, Taylor/Francis (1997)

Y. R. Shen: The Principles of Nonlinear Optics, Wiley (2002)

K. H. Bennemann: Nonlinear Optics in Metals, Oxford University (1999)

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Intensive Week: Advanced Topics in Photonics and Quantum Optics (E) - physics737

Course	**Intensive Week: Advanced Topics in Photonics and Quantum Optics (E)**
Course No.	physics737

Category	Type	Language	Teaching hours	CP	Semester
Elective	Combined lecture, seminar, lab course	English	3	4	WT/ST

Requirements for Participation:

Preparation: Fundamentals of optics, fundamentals of quantum mechanics

Form of Testing and Examination: Seminar or oral examination

Length of Course: 1 - 2 weeks

Aims of the Course: The intensive course will convey the basics of a recent topic in photonics or quantum optics in theory and experiments. Guided by a combination of lectures, seminar talks (based on original publications) and practical training, the participants will gain insight into recent developments in photonics/quantum optics.

Contents of the Course: Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature: Will be given in the lecture

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Lecture on Advanced Topics in Quantum Optics (E) - physics738

Course	**Lecture on Advanced Topics in Quantum Optics (E)**
Course No.	physics738

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT/ST

Requirements for Participation:

Preparation: Fundamentals of Quantum Mechanics, Atomic Physics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work within the exercises

Length of Course: 1 semester

Aims of the Course: The goal of the course is to introduce the students to a special field of research in quantum optics. New research results will be presented and their relevance is discussed.

Contents of the Course: Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature: Will be given in the lecture

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Lecture on Advanced Topics in Photonics (E/A) - physics739

Course	**Lecture on Advanced Topics in Photonics (E/A)**
Course No.	physics739

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	2+1	4	WT/ST

Requirements for Participation:

Preparation: Optics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work within the exercises

Length of Course: 1 semester

Aims of the Course: The goal of the course is to introduce the students to a special field of research in photonics. New research results will be presented and their relevance is discussed.

Contents of the Course: Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature: Will be given in the lecture

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Hands-on Seminar: Experimental Optics and Atomic Physics (E/A) - physics740

Course	**Hands-on Seminar: Experimental Optics and Atomic Physics (E/A)**
Course No.	physics740

Category	Type	Language	Teaching hours	CP	Semester
Elective	Laboratory	English	2	3	WT/ST

Requirements for Participation:

Preparation: Fundamentals of optics and quantum mechanics

Form of Testing and Examination: Credit points can be obtained after successful carrying out the experiments and preparing a written report on selected experiments

Length of Course: 1 semester

Aims of the Course: The students learn to handle optical setups and carry out optical experiments. This will prepare participants both for the successful completion of research projects in experimental quantum optics/photonics and tasks in the optics industry.

Contents of the Course:

Practical training in the field of optics, where the students start their experiment basically from scratch (i.e. an empty optical table). The training involves the following topics:

- diode lasers
- optical resonators
- acousto-optic modulators
- spectroscopy
- radiofrequency techniques

Recommended Literature: Will be given by the supervisor

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Modern Spectroscopy (E/A) - physics741

Course	**Modern Spectroscopy (E/A)**
Course No.	physics741

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	2+1	4	WT/ST

Requirements for Participation:

Preparation: Fundamentals of Optics, Fundamentals of Quantum Mechanics

Form of Testing and Examination: Requirements for the examination (oral or written): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: The aim of the course is to introduce the students to both fundamental and advanced concepts of spectroscopy and enable them to practically apply their knowledge.

Contents of the Course:

Spectroscopy phenomena - time and frequency domain;

high resolution spectroscopy;

pulsed spectroscopy; frequency combs;

coherent spectroscopy;

nonlinear spectroscopy: Saturation, Raman spectroscopy, Ramsey spectroscopy.

Applications of spectroscopic methods (e.g. Single molecule spectroscopy; spectroscopy at interfaces & surfaces, spectroscopy of cold atoms; atomic clocks; atom interferometry)

Recommended Literature:

W. Demtröder; Laser spectroscopy (Springer 2002)

S. Svanberg; Atomic and molecular spectroscopy basic aspects and practical applications (Springer 2001)

A. Corney; Atomic and laser spectroscopy (Clarendon Press 1988)

N. B. Colthup, L. H. Daly, S. E. Wiberley; Introduction to infrared and Raman spectroscopy (Academic Press 1990)

P. Hannaford; Femtosecond laser spectroscopy (Springer New York 2005)

C. Rulliere; Femtosecond laser pulses: principles and experiments (Springer Berlin 1998)

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Ultracold Atomic Gases (E/T) - physics742

Course	**Ultracold Atomic Gases (E/T)**
Course No.	physics742

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	3+1	6	WT

Requirements for Participation:

Preparation: Quantum Mechanics

Form of Testing and Examination: Requirements for the examination (written or oral): successful work with the exercises

Length of Course: 1 semester

Aims of the Course: This lecture discusses both the experimental and theoretical concepts of ultra-cold atomic gases.

Contents of the Course:

Almost hundred years ago, in 1924, A. Einstein and S.N. Bose predicted the existence of a new state of matter, the so-called Bose-Einstein condensate. It took 70 years to successfully realize this macroscopic quantum state in the lab using ultracold atomic gases (Nobel prize 2001). The main challenge was to achieve cooling to Nanokelvin temperatures, the coolest temperatures ever reached by mankind. Nowadays, ultracold gases are exciting systems to study a broad range of quantum phenomena. These phenomena range from the direct observation of quantum matter waves and superfluidity over the creation of artificial crystal structures as analogous to solids, to the realization of complex quantum phase transitions of interacting atoms, e.g. the formation of a bosonic Mott-insulator or the BCS superconducting state for Fermions. In this lecture we will discuss both the experimental and theoretical concepts of ultra-cold atomic gases.

Outline: Introduction and revision of basic concepts, Fundamentals of atom-laser interaction

Laser cooling & trapping, Bose-Einstein condensation of atomic gases. Dynamics of Bose-Einstein condensates

Optical lattices: strongly interacting atomic gases and quantum phase transitions

The crossover of Fermi-gases between a BCS superconducting state and a Bose-Einstein condensate of molecules.

Recommended Literature: C. J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases (Cambridge University Press)

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Platforms for Quantum Technologies (E) - physics743

Course	**Platforms for Quantum Technologies (E)**
Course No.	physics743

Category	**Type**	**Language**	**Teaching hours**	**CP**	**Semester**
Elective	Lecture with exercises	English	2 weeks fulltime	5	WT/ST

Requirements for Participation:

Preparation: Major courses of the 1st MSc term, for example, “Advanced Atomic, Molecular and Optical Physics”, “Quantum Optics”, “Advanced Quantum Theory”, “Theoretical Condensed Matter Physics”

Form of Testing and Examination: written exam

Length of Course: 2 weeks

Aims of the Course: Students receive an introduction into quantum technologies both theoretically and experimentally. Focus is on the theoretical foundations of quantum information processing, and experimental platforms primarily used in Bonn (Atomic, molecular and optical systems), Cologne (topological materials) and Aachen (spin & superconducting architectures) in the context of the Excellence Cluster ML4Q.

Contents of the Course:

1. Basics of quantum information processing
2. Atomic, molecular and optical platforms, quantum simulation
3. Solid-state platforms. Focus on quantum computation. Spin qubits, superconducting qubits;
4. Topological platforms, Topological materials, Topological architectures

Recommended Literature:

Nielsen & Chuang "Quantum information processing"

Pethick/Smith "Bose-Einstein condensation"

Lecture notes will be distributed for selected topics

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Internships in the Research Groups - physics799

Course	**Internships in the Research Groups**
Course No.	physics799

Category	Type	Language	Teaching hours	CP	Semester
Elective	Research Internship	English		4	WT/ST

Requirements for Participation: Students are asked to contact one of the BCGS lecturers prior to the start of their internship. Lecturers provide help if needed to find a suitable research group and topic. Not all groups may have internships available at all times, thus participation may be limited.

Preparation: A specialization lecture from the research field in question or equivalent preparation.

Form of Testing and Examination: A written report or, alternatively, a presentation in a meeting of the research group.

Length of Course: 4-6 weeks

Aims of the Course: Students conduct their own small research project as a part-time member of one of the research groups in Bonn. The students learn methods of scientific research and apply them to their project.

Contents of the Course:

One of the following possible items:

- setting up a small experiment,
- analyzing data from an existing experiment,
- simulating experimental situations,
- numerical or analytical calculations in a theory group.

Recommended Literature: provided by the supervisor within the research group.

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