Advanced Topics In Physics

2022-2023

This curricular unit is composed of several modules described below. All students are expected to choose 4 modules. To complete this unit they must be approved in three modules.
Timetables will be arranged after students choices are known. Modules take usually 5/6 weeks with 3/4 contact hours per week.

Modules

1. **Advanced Materials Preparation and Characterization (AMPC)**, Bernardo Almeida, U Minho.
2. **Clean Room and Micro-fabrication (CRMF),** Paulo Marques, João Oliveira Ventura, U. Porto.
3. **Spectroscopic techniques for the characterization of materials** (STCM), Rute André, Luis Carlos and Luis Cadillon Costa, U. Aveiro.
4. **Group Theory and applications to Condensed Matter Physics** (GTACMP), Joaquim Agostinho Moreira, U. Porto
5. **Introduction to Topological Matter(ITM),** Eduardo Castro, U. Porto
6. **Lasers, optics and photonics** (LOP), Mario Ferreira, U. Aveiro. (VC)
7. **Graphene plasmonics (GP),** Yuli Bludov (U. Minho)
8. **Computational Physics** (CP), Antonio Luis Ferreira, J. Pedro Coutinho U. Aveiro.
9. **Data Analysis in Particle Physics (DAPP)**, Nuno Castro (U Minho)
10. **Experimental Particle and Astroparticle Physics (EPAP)**, Nuno Castro, U. Minho
11. **Climate variability and change**, Alfredo Rocha (U Aveiro)
12. **Numerical simulation of the atmosphere and ocean** (NSAO), José Fortes, U Aveiro
13. T**he Weather Research and Forecasting (WRF) model**, David Carvalho U. Aveiro
14. **Optical fiber-based components and devices (OFBCD)**, Marta Ferreira, U. Aveiro
15. **Dualidade ADS/CFT,** João Caetano, Antonio Antunes, Miguel Costa
16. **Quantum Field Theory,** Antonio Antunes, João Caetano, Miguel Miguel Costa

Jury Panels

1. AMTC: Bernardo Almeida, João Ventura,
2. CRMF: João Oliveira Ventura; Paulo Marques, Bernardo Almeida
3. STCM: Rute André, Luís Carlos, Luís Manuel Cadillon Costa
4. GTACMP: Joaquim Agostinho Moreira, João Lopes dos Santos
5. ITM: Eduardo Castro, João Lopes dos Santos
6. LOP: Mário Ferreira, Manuel Marques
7. GP: Yuliy Bludov, Nuno Peres
8. CP: António Luís Ferreira, J. Pedro Coutinho
9. DAPP: Nuno Castro, António Morais, Miguel Romão
10. EPAP: Nuno Castro, Miguel Romão, Raul Sarmento
11. CVC: Alfredo Rocha, João Dias, Jesus Dubert
12. NSAO: José Fortes, João Dias, Jesus Dubert
13. WRF: David Carvalho, João Dias, Jesus Dubert
14. OFBCD: Marta Ferreira, Manuel Marques
15. João Caetano, Antonio Antunes, Miguel Costa
16. Antonio Antunes, João Caetano, Miguel Miguel Costa

Curricular Unit

Advanced Physics Topics

Module

Advanced materials preparation and characterization (AMPC)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Bernardo Almeida, U. Minho

Summary of Contents

Thin film preparation. Sputtering. Magnetron sputtering. Applications.
Laser Ablation deposition of thin films and nanostructures. Applications.
Structure and microstructure. X-ray diffraction. Low angle X-ray scattering, reflectometry, grazing incidence. Scanning electron microscopy (SEM). Transmission electron microscopy (TEM)
Infrared and Raman Spectroscopies. Lattice dynamics. Experimental setups. Applications.
Electrical properties. Dielectric relaxation. Impedance spectroscopy. Time and frequency domains. Experimental setups. Electrical resistivity. Magnetoresistance.
Magnetic properties. Magnetic interactions and magnetization. Magnetometry. Measurement techniques.
Optical properties. Reflectance and transmittance. Absorption. Photoluminescence. Ellipsometry.

Evaluation

Final exam

Jury

Bernardo Almeida, João Ventura

Curricular Unit

Advanced Physics Topics

Module

Clean Room and Micro-fabrication (CRMF)

Type

Practical instruction

Contact hours

18

Professor/Researcher in charge

Paulo Vicente Marques/João Ventura

Summary of Contents

This course will introduce, in a hands-on approach, the main microfabrication and deposition techniques used to produce functional devices in a Clean Room environment. Basic training in the use of a Clean Room, including basic facility description, operating procedures and safety instructions, will be provided. Ion beam deposition, resistive and electron-beam evaporation will be used to grow metallic and insulating thin films. The resolution and minimum feature size attainable by optical lithography will be studied using Direct Write Laser and Mask Alignment systems. Pattern transfer techniques (dry and wet etching and lift-off) will allow the comparison of their selectivity, anisotropy and etching rate. Basic characterization of the produced structures will be performed using optical microscopy and perfilometry, to extract relevant parameters (thin film roughness, thickness, deposition rates and uniformity; feature sizes, distributions, etching profiles). This module will take place in the recently installed Clean Room of the Porto University, CEMUP MNTEC.

Evaluation

Essay and oral presentation

Jury

João Oliveira Ventura; Paulo Marques, Bernardo Almeida

Curricular Unit

Advanced Physics Topics

Module

Spectroscopic techniques for the characterization of materials (STCM)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Rute André e Luís Carlos, and Luis Cadillon Costa, U. Aveiro.

Summary of Contents

Optical properties;
Photoluminescence in steady state and time resolved (emission spectra and emission decay curves) modes.
Quantification of the emission features (Absolute quantum yield, photometric and radiometric parameters, colour coordinates)
Ellipsometry. Fundamentals and applications. Structural modelling.
Electric properties; Electronic Paramagnetic Resonance

Evaluation

Written Test (3h).

Jury

Maria Rute André, Luís Carlos, Luis Cadillon Costa

Curricular Unit

Advanced Physics Topics

Module

Group Theory and Applications to Condensed Matter Physics

Type

Tutorial: Reading and Study assignment

Contact hours

18

Professor/Researcher in charge

Joaquim Agostinho Moreira , U. Porto

Summary of Contents

Representations theory and basic theorems. Character of a representation and basis functions.
Direct product and its representations. Application to selection rules and splitting of atomic levels in a crystal field.
Space groups in real space and in the reciprocal space. Symmetry of the k vectors and the group of the wave vector. Representations of a space group. Little group and stars. Factor group analysis and the Γ point. Points for k≠0. Compatibility relations.
Applications to lattice vibrations and electronic energy levels. Energy band models based on symmetry. Spin-orbit coupling in solids and double groups and application to energy bands with spin.
Time reversal symmetry. The Magnetic Groups and their Co-representations. Properties of the magnetic point groups.

References

Group Theory. M. S. Dresselhaus, G. Dresselhaus, and A. Jorio. Springer. 2008
The Mathematical Theory of Symmetry in Solids. Representation Theory for Point Groups and Space Groups. C. Bradley and A. Cracknell. Oxford Classic Texts in the Physical Sciences. 2010.
J. L. Ribeiro. Phys. Rev. B 76, 144417 (2007).
J. L. Ribeiro and L. G. Vieira. Phys. Rev. B 82, 064410 (2010)
I. Urcelay-Olabarria, J. M. Perez-Mato, J. L. Ribeiro, J. L. García-Muñoz, E. Ressouche, V. Skumryev, and A. A. Mukhin. Phys. Rev. B 87, 014419 (2013).

Jury

Joaquim Agostinho Moreira, João Lopes dos Santos

7. Curricular Unit

Advanced Physics Topics

Module

Introduction to Topological Matter

Type

Tutorial

Contact hours

18

Professor/Researcher in charge

Eduardo Castro, UPorto

Summary of Contents

Topological insulators in 1D; Berry phase in electronic systems; the Chern number as a topological invariant in 2D; the quantum Hall effect, Chern insulators and bulk edge correspondence; quantum spin Hall systems; 3D topological insulators; topological superconductors and Majorana modes; topological classification; gapless topological systems (Weyl and Dirac semimetals).

References

"Berry phase effects on electronic properties", D. Xiao, M.-C. Chang, Q. Niu, Rev. Mod. Phys. **82**, 1959 (2010)

"Topological insulators", M. Hasan and C. Kane, Rev. Mod. Phys. **82**, 3045 (2010)

"Topological insulators and superconductors", X. Qi and S.-C. Zhang, Rev. Mod. Phys. **83**, 1057 (2011)

"Berry Phases in Electronic Structure Theory", D. Vanderbilt, Cambridge University Press, 2018

"Topological Insulators and Topological Superconductors", B. A. Bernevig, Princeton University Press, 2013

"Topological Insulators", S. Shen, Springer, 2012

https://topocondmat.org/

Evaluation

Written Report with oral presentation or Written Report.

Jury

Eduardo Castro, João Lopes dos Santos

Curricular Unit

Advanced Physics Topics

Module

Lasers, optics and photonics (LOP)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Mario Ferreira, U. Aveiro

Summary of Contents

This module will cover several topics that illustrate the revolution in optical area during the last decades, following the invention of the LASER. Special attention will be paid to some latest developments within optical communications and nonlinear optics.

Evaluation

3 Homework problems (50%) and final exam (50%)

Jury

Mário Ferreira, Manuel Marques

Curricular Unit

Advanced Physics Topics

Module

Graphene plasmonics (GP)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Yuliy Bludov

Summary of Contents

This module exposes the students to basic concepts of the rapidly emerging area of graphene plasmonics. The practical interest of this area is determined by the small wavelength of the surface polaritons, when compared to that of bulk electromagnetic waves, which allows the miniaturization of photonic components. Furthermore, this gives rise to a higher localization of the surface polaritons, which are characterized by lower damping, in comparison with noble metals. The possibility to dynamically tune graphene's conductivity through the variation of a gate voltage introduces and extra degree of freedom into the problem. In this module students contact with basic knowledge on the optical properties of graphene and on the properties of surface polaritons (a special kind of electromagnetic waves, propagating along surfaces and interfaces) both in noble metals and in graphene (a 2D carbon material). The theory of surface polaritons in graphene, dispersion relations and methods for exciting these type of waves, is explained. Finally the description of experimental works as well as the corresponding operational principles will be detailed. Detailed program:
1.) electronic properties of graphene and its optical conductivity;
2.) Drude model for metals and for graphene;
3.) Surface plasmon-polaritons in noble metals;
4.) Surface plasmon-polaritons in graphene;
4.) Methods for exciting surface plasmon-polaritons;
5.) Some experiments using the excitation of surface plasmon-polaritons;
6.) Localized plasmons in graphene based nano-structures.

Evaluation

1.) For new comers to the subject: One written report and one introductory computational project.

2.) For experts on the topic: One research project, which must be presented in the end of the semester in front of the class.

Note: Any student can opt for one or the other type of evaluation

Jury

Nuno Peres, Yuliy Bludov

Curricular Unit

Advanced Physics Topics

Module

Computational Physics (CP)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Antonio Luis Ferreira, U. Aveiro, J Pedro Coutinho , U. Aveiro

Summary of Contents

Part 1 (9 hours) Introduction to Monte Carlo Methods
Monte Carlo Methods in Statistical Physics. Markov Chains: Chapman-Kolmogorov equation; Transient and stationary regimes; Detailed balance.
Monte Carlo Integration: Hit or Miss Monte Carlo; integration as an average calculation; random Sampling; importance sampling; Markov Chain Monte-Carlo; Metropolis algorithm
Applications to Statistical Physics: ergodicity; detailed balance; equilibration; estimating errors.
Advanced Monte Carlo methods
Part 2: Density Functional Theory: Modeling Solids, Surfaces and Molecules
Introduction to Density Functional Theory; The many-body Hamiltonian and the exchange-correlation functional; Pseudo-potentials; Valence states and basis functions; Brillouin zone sampling methods; Numerical implementation.
Applications to solid-state problems, surfaces and molecules
Hands-on session: “Pick a problem for your classmate”

References

Understanding Molecular Simulations, Daan Frenkel and Berend Smit
Computer Simulation of Liquids, M P Allen and D J Tildesley
Monte Carlo Methods in Statistical Physics, by Mark Newman, G T Barkema
Density functional theory: An introduction, Nathan Argaman and Guy Makov, American Journal of Physics 68, 69-79, (2000); doi:10.1119/1.19375; arXiv:physics/9806013
The ABC of DFT, Kieron Burke, https://dft.uci.edu/doc/g1.pdf

Evaluation

Exam with computational exercises (part1); Exam with computational exercises (part2).

Jury

António Luís Ferreira, J Pedro Coutinho

Curricular Unit

Advanced Physics Topics

Module

Data Analysis in Particle Physics

Type

Tutorial

Contact hours

18h

Professor in charge

Nuno Castro

Summary of Contents

The ability to fully explore the physics potential of the Large Hadron Collider (LHC) data relies on the ability to efficiently analyze the available dataset, maximizing the sensitivity to subtle signals hidden in a huge amount of background events. In the present tutorial will allow the students to acquire, in a supervised way, competences on advanced data analysis techniques, as well as expertise on some advanced tools commonly used in the high energy physics community.

The tutorial will consist on the development by the students, supervised by Professor, of a practical project based on the analysis of the ATLAS Open Dataset. The use of machine learning tools will be exercised, aiming to improve the discriminating power of a data analysis in order to maximize the sensitivity to the chosen signal events.

Evaluation

The evaluation will be done based on the discussions held during the contact hours, as well as on the final project, according to the following weights:

- Discussions during the contact hours: 10%
- Quality of the developed project: 50%
- Defense and presentation of the developed project: 40%

Jury

Nuno Castro, António Morais, Miguel Romão

Curricular Unit

Advanced Physics Topics

Module

Experimental Particle and Astroparticle Physics

Type

Tutorial

Contact hours

18 TP

Professor/Researcher in charge

Nuno Castro, Miguel Romão, Raul Sarmento

Summary of Contents

This course involves the study of advanced analysis methods for PhD students within the field of Particle Physics. Following a theoretical introduction to the Standard Model and model building beyond it, a review of recent experimental results from colliders will be done. The course will end with a review of astroparticle physics and challenges for the future of the field.

Evaluation

Students are expected to actively follow the lectures and to participate in the discussions. The grading plan involves attendance and participation in discussions, individual and team work as well as a final exam.

Coursework will be weighted as follows:

Discussions at the classes	10%
Theory exam	40%
Oral discussion of a research paper	50%

Jury

Nuno Castro, Miguel Romão, Raul Sarmento

Curricular Unit
Advanced Physics Topics

Module
Climate variability and change

Type
Tutorial: Reading and Study assignment

Contact hours
18

Professor/Researcher in charge
Alfredo Rocha

Summary of Contents

1.The climate system.
2. Interaction amongst climate sub-systems.
3. Feedbacks in the climate system.
4. Forcing agents of climate.
5. Climate variability and change simulations due to external forcing.

References

National Research Council, 2003. Understanding climate change feedbacks. The National Academies Press. 152 p.

Peixoto and Oort, 1992. Physics of climate. American Institute of Physics. 520 p.

Solomon, Qin, Manning, Chen, Marquis, Averyt, Tignor and Miller (eds.), 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge Uni. Press. Cambridge, United Kingdom and New York, NY, USA

Santos and Miranda, 2007. Alterações climáticas em Portugal. Cenários, impactos e medidas de adaptação. Gradiva. 503 p.

Evaluation
Elaboration of a monograph and its oral presentation

Jury
Alfredo Rocha, João Dias, Jesus Dubert

Curricular Unit
Advanced Physics Topics

Module
Numerical simulation of the atmosphere and ocean- (NSAO)

Type
Tutorial: Reading and Study assignment

Contact hours
18

Professor/Researcher in charge
José Fortes

Summary of Contents
1. History of numerical modelling in atmospheric/oceanic sciences
2. Conservation equations
3. Methods to solve the equations
4. Vertical coordinates
5. Initial conditions
6. Data assimilation
7. Boundary conditions
8. Ensemble forecasting
9. Physic parametrizations

Bibliography

McGuffie and Henderson-Sellers, 2005. A modelling climate primer. Wiley. 280 p.
Washington and Parkinson, 2005. An introduction to climate modeling. Uni. Sci. Books. 353 p.
Krishnamurti, Bedi and Hardiker, 1998. An introduction to global spectral modelling. Oxford Uni. Press. 251 p.
Pielke, 2002. Mesoscale meteorological modelling. Academic Press. 676 p.
Dynamics of meteorology – Holton
Physics of climate – Peixoto and Oort
Lorenz, 1993. The essence of chaos. Uni. Washington Press. 227 p.

Evaluation
Elaboration of a monograph and its oral presentation

Jury

José Fortes, João Dias, Jesus Dubert

Curricular Unit
Advanced Physics Topics

Module
The Weather Research and Forecasting (WRF) model

Type
Tutorial: Reading and Study assignment

Contact hours
18

Professor/Researcher in charge
David Carvalho

Summary of Contents
The WRF model development.
Data assimilation.
Physics parametrization development and testing.
Regional climate simulations with WRF.
Model evaluation.

References
Skamarock, W.C.; Klemp, J.B.; Dudhia, J.; Gill, D.O.; Barker, D.M.; Duda, M.G.; Huang, X.-Y.; Wang, W.;Powers, J.G. A Description of the Advanced Research WRF Version 3; National Center for Atmospheric Research Boulder, CO, USA, 2008.

Evaluation
Elaboration of a monograph and its oral presentation

Juri
David Carvalho, João Dias, Jesus Dubert

Curricular Unit

Advanced Physics Topics

Module

Optical fiber-based components and devices

Type

Tutorial

Contact hours

18

Professor/Researcher in charge

Marta Sofia dos Anjos Ferreira

Summary of Contents

The design of new optical fiber sensors relies not only on the sensing element itself, but also on the use of specific components that enable the desired propagation characteristics, or even their enhancement. In this module, different components/ devices will be studied in detail:

Optical fiber components: couplers / splitters, optical circulators, isolators, collimators, wavelength division multiplexers and types of fiber cables

Fiber polarization management: polarization controllers, Faraday rotator mirrors, fiber polarizers, polarization scramblers

Optical fiber multimode sensors: from design to applications. Here, the different components will be evaluated in a few practical examples.

Evaluation

Written report.

Bibliography

Del Vilar, I., Matias, I. R., 2021. Optical fibre sensors: fundamentals for development of optimized devices, 1st Edition, IEEE Press Wiley, New Jersey.

Mitschke, F., 2016. Fiber Optics Physics and Technology, 2nd Edition, Springer – Verlag, Germany.

Fang, Z., Chin, K.K., Qu, R., Cai, H., 2012. Fundamentals of optical fiber sensors, 1st Edition, Wiley, New Jersey.

Jury

Marta Sofia dos Anjos Ferreira, Manuel Marques