Advanced Topics In Physics

2021-2022

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. The Physics of Electronic Materials and Devices (PEMD), João Pedro Alpuim, U. Minho
3. Clean Room and Micro-fabrication (CRMF), Paulo Marques, João Oliveira Ventura, U. Porto.
4. Nanomagnetism (NM),J E Araújo, Vitor Amaral, U. Porto, U. Aveiro.
5. Spectroscopic techniques for the characterization of materials (STCM), Rute André e N. Sobolev, and Luis Cadillon Costa, U. Aveiro.
6. Group Theory and applications to Condensed Matter Physics (GTACMP), Joaquim Agostinho Moreira, U. Porto
7. Introduction to Topological Matter(ITM), Eduardo Castro, U. Porto
8. Lasers, optics and photonics (LOP), Mario Ferreira, U. Aveiro. (VC)
9. Introduction to Nonlinear and Ultra-fast Optics (INUO), Manuel Marques, U Porto.
10. Graphene plasmonics (GP), Yuli Bludov (U. Minho)
11. Computational Physics (CP), Antonio Luis Ferreira, J. Pedro Coutinho U. Aveiro.
12. Biomedical Signal and Image Analysis (BSIA), Ana Paula Rocha U. Porto
13. Biophotonics: sensing and imaging (BPSI) Carla Carmelo Rosa, J. Agostinho Moreira, U. Porto
14. Nanomedicine (NMD): Science and Applications, André Pereira U. Porto.
15. Black holes: theory and recent observations (BH) , Carlos Herdeiro, U Aveiro
16. Data Analysis in Particle Physics (DAPP), Nuno Castro (U Minho)
17. Experimental Particle and Astroparticle Physics (EPAP), Nuno Castro, U. Minho
18. Standard Model I, (SMI) António Morais, U Aveiro
19. Standard Model II, (SMII) António Morais, U Aveiro
20. Climate variability and change, Alfredo Rocha (U Aveiro)

21. Numerical simulation of the atmosphere and ocean (NSAO), José Fortes, U Aveiro
22. The Weather Research and Forecasting (WRF) model, David Carvalho U. Aveiro

Jury Panels

1. AMTC: Bernardo Almeida, João Ventura,
2. PEMD: Pedro Alpuim, Bernardo Almeida, Joaquim Leitão
3. CRMF: João Oliveira Ventura; Paulo Marques, Bernardo Almeida
4. NM: João Pedro Araújo, Vitor Amaral, João Ventura
5. STCM: Rute André, Sobolev, Luís Manuel Cadillon Costa
6. GTACMP: Joaquim Agostinho Moreira, João Lopes dos Santos
7. ITM: Eduardo Castro, João Lopes dos Santos
8. LOP: Mário Ferreira, Manuel Marques
9. INUO: Manuel Marques, Mário Ferreira
10. GP: Yuliy Bludov, Nuno Peres
11. CP: António Luís Ferreira, J. Pedro Coutinho
12. BSIA, Ana Paula Rocha, André Marçal
13. BPSI: Carla Carmelo Rosa, J. Agostinho Moreira
14. NMD: André Miguel Trindade Pereira, Carla Rosa, Vitor Amaral
15. BH: Carlos Herdeiro, Pedro V. P. Cunha and Nicolas Sanchis Gual
16. DAPP: Nuno Castro, António Morais, Miguel Romão
17. EPAP: Nuno Castro, Miguel Romão, Raul Sarmento
18. SMI: António Morais, Nuno Castro, António Onofre
19. SMII: António Morais, Nuno Castro, António Onofre
20. CVC: Alfredo Rocha, João Dias, Jesus Dubert
21. NSAO: José Fortes, João Dias, Jesus Dubert
22. WRF: David Carvalho, João Dias, Jesus Dubert

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

The Physics of Electronic Materials and Devices (PEMD)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

João Pedro Alpuim; palpuim@fisica.uminho.pt

Summary of Contents

Continued miniaturization of silicon devices paved the way for a host of electronic appliances that revolutionized our day-to-day life during the last half century. Nanotechnology is currently introducing a new level of complexity into very small objects that in turn will allow this dizzying pace of miniaturization not only to keep up but possibly to accelerate.

This module is designed to provide a broad view of electronic materials and devices and their fabrication techniques, going from the well-established Si-based technology, through magnetic devices for data storage, up to sensors based on new 2D materials and their applications. The module includes a session hosted by INL in Braga, where students will be introduced to the state-of-the-art facilities that are available at the institute.

Electrons in solids (5 hours)
Electrons in a periodic field of a crystal
Energy bands in metal and semiconductor crystalline solids
Band structures in 3D, 2D and 1D
Electrons in nanostructures: Landauer resistance, Coulomb blockade and resonant tunneling

Micro/nanoelectronic semiconductor devices (5 hours)
The p-n junction and the bipolar transistor
The LED and the LASER
The field-effect transistor: NMOS, CMOS and 2D materials FETs

Macroelectronic devices (2 hours)
Solar cells
MEMS and NEMS devices
Displays

Sensors and data storage (3 hours)
Biosensors

Magnetic devices
Top down fabrication of micro and nanostructures (3 hours)

Bibliography

Solid State Physics, N. W. Ashcroft, N. D. Mermin, Saunders College Publishing. Harcourt College Publishers. Fort Worth Philadelphia (1976).

Physics of Semiconductor Devices, S.M. Sze, K.K. Ng, J. Wiley & Sons Inc., New York, 3rd Edition (2006).

Introduction to Nanoelectronics, by V.V. Mitin, V.A. Kochelap and M.A. Stroscio, Cambridge University Press, Cambridge (2008).

Introduction to Nanoscience, S.M. Lindsay, Oxford University Press, Oxford (2010).
Fundamentals of microfabrication: the science of miniaturization, Marc J. Madou, Taylor & Francis, Inc., 2nd Edition, New York (2002).

Evaluation

Student grading will be based on a final individual exam containing conceptual questions and problems to be solved by the student. Grading will be based on a 0-20 scale and to get approval the student must obtain at least grade 10.

Students can also adhere voluntarily to a scheme of periodic evaluation of their work, based on the weekly resolution of a problem chosen by the professor and to be returned the following class. Students can seek information of any sort in order to solve the proposed problem but they compromise to do it individually. In every class, 20 minutes of lecture time will be devoted to the discussion of the solution of that week's problem and the methods used to obtain it. Any of the students having returned the problem solved in a particular week can be asked by the professor to introduce that discussion orally, based on the solution and the way he/she obtained it. In case he or she fails to do so, the problem will not be considered for evaluation. There will be a series of 8 weekly problems, each valued 2.5 points, and totalizing 20 points. Each student can enter/leave this evaluation program freely. The student will be approved in this scheme when he/she accumulates at least 10 points. In this case he/she can decide not to present himself/herself to the final exam in which case his/her final grade will be the sum of the points accumulated in the periodic evaluation of his/her work.

Jury

Pedro Alpuim, Bernardo Almeida, Joaquim Leitão

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

Nanomagnetism (NM)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

João Pedro Araújo, U. Porto, Vitor Amaral (U. Aveiro)

Summary of Contents

Magnetism: basic macroscopic concepts. Magnetic moment, diamagnetism, paramagnetism.
Macroscopic description: field and temperature dependence of a spin ½ paramagnetic system.
Spin, orbital and magnetic momentum. Electronic configurations, Hund rules, 3d and 4f atoms/ions
Brillouin function, Curie law, Pauli paramagnetism. Perturbation theory and Van Vleck paramagnetism. Magnetic interactions, microscopic description, ferromagnetism, ferrimagnetism, antiferromagnetism. Electronic correlations. Mean field models. Curie-Weiss law
The Landau theory of phase transitions: order parameters, equation of state, critical temperature and exponents, Arrott-Belov plots, coupled magneto-volume phase transitions, the magnetocaloric effect. The Bean-Rodbell model, scaling plots, critical phenomena, the Ising and Heisenberg models, the Arrott-Noakes equation of state.
Magnetic domains. Magnetostatic energy, anisotropy energy. Domain walls.
Magnetic nanoparticles, Stoner-Wolfhart model.
Superparamagnetism, relaxation, Néel and Brown mechanisms. Energy distributions, dipolar interactions, surface effects. Exchange bias. Applications: recording, hyperthermia and magnetic resonance imaging.

Evaluation

Written essay on selected topics. Oral presentation (15’) followed by discussion (10’).

Jury

João Pedro Araújo, Vitor Amaral, João Ventura

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 N. Sobolev, 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, Nikolai Andreevitch Sobolev, 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 Corepresentations. 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

Introduction to Nonlinear and Ultra-fast Optics (INUO)

Type

Mixed Lecture/Tutorial

Contact hours

18

Professor/Researcher in charge

Manuel Marques, UPorto

Summary of Contents

Introduction (history and overview of nonlinear and ultrafast optics); Frequency mixing (coupled equations for two and three-wave mixing processes, Manley–Rowe relations, quasi-phase matching); Harmonic generation with Gaussian beams; Crystal optics (brief review); Nonlinear optics in crystals; Third-order nonlinear processes (including the intensity-dependent refractive index and self-phase modulation); Dispersion and optical pulses; Nonlinear optics with pulses.

References

Geoffrey New; Introduction to Nonlinear Optics, Cambridge University Press, 2014. ISBN: 1107424488

Robert Boyd; Nonlinear Optics - Third Edition, 2008

Evaluation

Written Report

Jury

Manuel Marques, Mário Ferreira

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

Biomedical Signal and Image Analysis

Type

Lecture course

Contact hours: 18

Professor/Researcher in charge

Ana Paula Rocha

Summary of Contents

Digital and Statistical Signal Processing review. Biomedical Signal Processing: Short introduction. Selected advanced analysis tools of current modern biomedical signal processing and application, such as: time-frequency, time-scale and wavelet analysis; optimal, adaptive and Kernel methods; complexity/ nonlinear dynamics modeling; PCA/ICA multivariate analysis.
Image Processing fundamentals. Image Segmentation, classification and annotation. The Radon Transform and image reconstruction.

The focus in in 2020/21will be in Signal Processing Topics.

References

Semmlow,J.L., Griffel,B. 2014, Biosignal and Medical Image Processing, CRC Press, ISBN 978-1-4665-6737-5

K.L. Blinovska and J Zygierewicz,Pratical Biomedical Signal Analysis using Matlab, Series in Medical Physics and Biomedical Engineering, CRC Press 2012

S. Cerutti, C. Marchesi eds., Advanced Methods of Biomedical Signal Processing, IEEE Wiley, 2011.

Gonzalez, R.C., Woods, R.E., 2008, Digital Image Processing, Addison-Wesley, ISBN: 978-0-13-168728-8

C.L.Epstein, 2008, Introduction to the Mathematics of Medical Imaging, 2nd Edition, SIAM, ISBN 978-0-89871-642-9

Evaluation

Project

Jury

Ana Paula Rocha, André Marçal

13. Curricular Unit

Advanced Physics Topics

Module

Biophotonics: sensing and imaging

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Carla Carmelo Rosa, J. Agostinho Moreira

Summary of Contents

Optical properties of biological tissues, and the physics of light-tissue interactions
Characterization of bio-tissues: advanced optical imaging and light spectroscopy techniques
Light induced modifications of bio-tissues: clinical applications of lasers, and safety.
Vibrational spectroscopies: principles and applications. Instrumentation.
Biophysical applications of the micro-Raman spectroscopy. Biological vibrational imaging.
Surface-enhanced Raman spectroscopy (SERS): electromagnetic theory and Mie theory. Instrumentation. Single-molecule SERS. Nanosensors based on SERS.
SERS for biomedical diagnostics and molecular imaging.

Bibliography

Markolf H. Niemz; Laser-tissue interactions. ISBN: 978-3-540-72191-8, 2007.
R. Splinter; An introduction to biomedical optics. ISBN: 0-7503-0938-5, 2007.
Lihong V. Wang; Biomedical optics. ISBN: 978-0-471-74304-0, 2007.
Barry R. Masters; Confocal microscopy and multiphoton excitation microscopy. ISBN: 978-0-8194-6118-6, 2006.
Hans-Ulrich and Bing Yan (Eds). Infrared and Raman Spectroscopy of Biological Materials. Practical Spectroscopy Series. ISBN 0-8247-0409-6, 2001.
Katrin Kneipp, martin Moskovits and Harald Kneipp. Surface-Enhanced Raman Scattering, Physics and Applications. ISBN: 978-3-540-33566-5, 2006.
Influence of substrate temperature on the properties of pulsed laser deposited silver nanoparticle thin films and their application in SERS detection of bovine serum albumin. Koppole Kamakshi, J. P. B. Silva, K. C. Sekhar, Gregory Marslin, J. Agostinho Moreira, O. Conde, A. Almeida, M. Pereira, M. J. M. Gomes. Appl. Phys. B 122,108 (2016).Team, M. C. (2003).
Surface plasmon resonance coupled photoluminescence and resistive switching behavior of pulsed laser deposited Ag:SiC nanocermet thin films. Koppole Kamakshi, K C Sekhar, A Almeida, J Agostinho Moreira, M J M

Gomes. Plasmonics. DOI 10.1007/s11468-015-9915-4 (2015).

Evaluation

Jury

Carla Carmelo Rosa, J. Agostinho Moreira,

14. Curricular Unit

Advanced Physics Topics

Module

Nanomedicine: Science and Applications

Type

Lecture Course

Contact hours

18h

Professors/Researchers in charge

André Miguel Trindade Pereira

Summary of Contents

This course provides a thorough overview and a state-of-the-art of the exciting and emerging field of Nanomedicine which has already transformed the way that medical and healthcare solutions are developed and delivered.
The course has the following contents:
Introduction to Nanomedicine
This section will be focused on the introduction to Nanotechnology for Medicine and Healthcare. The basic concepts on nanomaterials in Medicine and the nanoscale relation to biological systems (cell, virus, blood) will be discussed. Toxicology and safety of nanomaterials will be presented since they are essential aspects when working in biomedical applications. Finally, innate and adaptive immune responses of biological systems to nanomaterials will end the first section.
Nano-Diagnostics
This section will be focused on the main applications of nanoparticles to the Nanomedicine field. An overview to nano-diagnostics will be provided, followed by the application of microvesicles and nanovesicles in health and disease. The engineered nanoparticles will be afterwards presented for:
Medical imaging (ultrasound, optical, computed tomography, magnetic resonance imaging and positron emission tomography);
ii) Cancer diagnostics: In vitro & In vivo diagnostics.
At the end, DNA sequencing and DNA microarrays for medical diagnostics will be presented.
Nanotechnologies for regenerative medicine and tissue engineering In this section will be discussed Nanomaterials for regeneration of bone and cartilage as well as scaffolding and nanocomposites for tissue engineering. Electrospinning in tissue engineering and nanomaterials in dentistry will be presented at the end of this section.
Nano-Biosensors
This section will be devoted to the main requirements of biosensing systems, being afterwards focused on electrochemical sensing and optical sensing methodologies. Nano-biosensors (devices) and the main challenges to validate biosensors in the clinical setting will be presented.
Nano-Pharmaceuticals

This section will be focused on nanotechnologies and nanoparticles for drug delivery and therapy, on in vivo location and biodistribution of nanoparticle. Nanoparticle targeting, bio-nanotherapeutics and nanopharmaceuticals will be discussed. A special focus on magnetic hyperthermia will be provided. Finally, the new trend on Theranostics, combining medical diagnosis with therapy, will be the last topic addressed in this section.

Trends, challenges and opportunities in Nanomedicine

In this section important aspects of Nanomedicine will be discussed such as, ethics, regulation approval in Nanomedicine and industrial perspectives. Finally, the market analysis, future trends and opportunities will be addressed.

Bibliography

[1] P.N. Prasad, "Introduction to Nanomedicine and Nanobioengineering", John Wiley & Sons Inc. (2012). [2] R. Bawa, G.F. Audette, I. Rubinstein, "Handbook of Clinical Nanomedicine: Nanoparticles, Imaging, Therapy, and Clinical Applications", CRC press, Taylor & Francis Group (2016). [2] A.M. Pereira, C. Pereira, A.S. Silva, D.S. Schmool, C. Freire, J.-M. Greneche, J.P. Araujo, "Unravelling the effect of interparticle interactions and surface spin canting in gamma-Fe2O3@SiO2 superparamagnetic nanoparticles", Journal of Applied Physics, 109 (2011) 114319.

Evaluation

Written essay on selected topics. Oral presentation (15') followed by discussion (10')

Jury

André Miguel Trindade Pereira, Carla Rosa, Vitor Amaral

Curricular Unit

Advanced Physics Topics

Module

Black holes: theory and recent observations

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Carlos Herdeiro

Summary of Contents

1) Black holes in General Relativity. The Kerr family of solutions and its properties. No hair theorems.
2) Black hole shadows: EHT observations and theoretical templates.
2a)- Hamiltonian-Jacobi formalism in General Relativity;
2b)- Geodesic Separability in the Kerr spacetime;
2c)- ISCO and time-like geodesics;
2d)- Spherical Photon Orbits and the black hole shadow;
2e)- The EHT observation and testing General relativity using the shadow of black holes;
2f)- The topological charge of a Light Ring orbit and its applications;
3) Gravitational waves: LIGO-Virgo detections and theoretical waveforms.
3a)- Linearized theory and quadrupole formula.
3b)- Introduction to Numerical Relativity and gravitational-wave extraction.
3c)- Gravitational-wave detections by LVK.
3d)- Exotic compact objects and how to find them

Evaluation

Problem sets and paper presentation.

Bibliography

https://arxiv.org/abs/gr-qc/9707012
https://arxiv.org/abs/1504.08209
https://arxiv.org/abs/1801.00860
Teo, E. General Relativity and Gravitation 35, 1909–1926 (2003). https://link.springer.com/article/10.1023/A:1026286607562
https://arxiv.org/pdf/1502.03808.pdf
https://arxiv.org/pdf/1410.7775.pdf

The Astrophysical Journal Letters, 875, nº1 https://iopscience.iop.org/article/10.3847/2041-8213/ab0ec7
https://arxiv.org/pdf/gr-qc/9506086
https://arxiv.org/abs/gr-qc/0507014
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.061102
https://arxiv.org/abs/2009.05376

Jury

Carlos Herdeiro, Pedro V. P. Cunha and Nicolas Sanchis Gual

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

Standard Model I

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

António Morais, U. Aveiro

Summary of Contents

1. Relativistic equations: Lorentz transformations; covariant formulation of Maxwell theory; gauge invatiance; Klein-Gordon and Dirac equations; Helicity and Chirality.
2. Lagrangian Formulation in field theory: The Euler-Lagrange equations; the Klein-Gordon, Dirac and Maxwell Lagrangians; continuous symmetries and the Noether Theorem.
3. Symmetry breaking: The abelian Higgs Mechanism; spontaneous and explicit symmetry breaking; the Goldstone Theorem.

Evaluation

Hand-in exercises	30%
Final exam	70%

Jury

António Morais, Nuno Castro, António Onofre

Curricular Unit

Advanced Physics Topics

Module

Standard Model II

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

António Morais, U. Aveiro

Summary of Contents

1. Group theory elements for Particle Physics: Lorentz and Poincaré groups; SU(N) groups, Young Tableau and tensor products.
2. The Standard Model: Yang-Mills theories; QCD and the electroweak sector; The Higgs Mechanism in the SM; mass generation and mixing.
3. Introduction to perturbation theory: Feynman rules in QED; amplitudes, cross-sections and decay widths calculation.
4. Beyond the Standard Model (topics to cover depend on available time): Neutrino masses; extended scalar sectors; vector-like leptons; leptoquarks; supersymmetry.

Evaluation

Hand-in exercises	30%
Final exam	70%

Jury

António Morais, Nuno Castro, António Onofre

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