Advanced Topics In Physics

2020-2021

(Provisional List)

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.[to be confirmed]
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, U. Porto, Vitor Amaral, U. Aveiro.[to be confirmed]
5. Spectroscopic techniques for the characterization of materials (STCM), Rute André e N. Sobolev, and Luis Carlos, U. Aveiro.
6. Scanning Microscopy Techniques and Electronic Microscopy (SMT), Andrei Kholkine and Augusto Barros Lopes (U. Aveiro)
7. Group Theory and applications to Condensed Matter Physics (GTACMP), Joaquim Agostinho Moreira, U. Porto
8. Introduction to Topological Matter(ITM), Eduardo Castro, U. Porto
9. Lasers, optics and photonics (LOP), Mario Ferreira, U. Aveiro.
10. Quantum information and applications, Ariel Guerreiro U Porto
11. Graphene plasmonics (GP), Yuli Bludov (U. Minho)
12. Computational Physics (CP), Antonio Luis Ferreira, J. Pedro Coutinho U. Aveiro.
13. Introduction to nano-optics (INO), Manuel J. Marques Orlando Frazão, (U.Porto)
14. Biomedical Signal and Image Analysis (BSIA), Ana Paula Rocha, André Marçal, U. Porto
15. Biophotonics: sensing and imaging (BPSI) Carla Carmelo Rosa, J. Agostinho Moreira, U. Porto [to be confirmed]
16. Nanomedicine (NMD): Science and Applications, André Pereira U. Porto.
17. Data Analysis in Particle Physics (DAPP), Nuno Castro (U Minho)
18. Experimental Particle and Astroparticle Physics (EPAP), Antonio Onofre, U. Minho
19. Correlations Effects in Low-Dimensional Materials and Systems (CELDM), Jose Carmelo, U.

Minho

Jury Panels

1. AMTC: Bernardo Almeida, João Ventura, Florinda Costa.
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 Martins Costa
6. SMTEM: Andrei Kholkine and Augusto Barros Lopes,
7. GTACMP: Joaquim Agostinho Moreira, João Lopes dos Santos, José Carmelo
8. ITM: Eduardo Castro, João Lopes dos Santos
9. LOP: Mário Ferreira, Manuel Marques, Helder Crespo
10. QuIA, Ariel Guerreiro, João Lopes dos Santos, Ricardo Dias
11. GP: Nuno Peres, Yuliy Bludov, João Lopes dos Santos
12. CP: António Luís Ferreira, J V Lopes , J. Pedro Coutinho
13. INO: Orlando Frazão, Manuel J. Marques, Mário Ferreira
14. BSIA, Ana Paula Rocha, André Marçal
15. BPSI Carla Carmelo Rosa, J. Agostinho Moreira
16. NMD André Miguel Trindade Pereira, Carla Rosa, Vitor Amaral
17. DAPP: Antonio Onofre, Nuno Castro, Antonio Morais
18. EPAP: Antonio Onofre, Nuno Castro, Antonio Morais
19. (CELDM) CJosé Carmelo, João Lopes dos Santos, Antonio Luís Ferreira

1. 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, Florinda Costa

2. 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

3. 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

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

4. 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

5. 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, 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 de Amorim e Sá Ferreira André, Nikolai Andreevitch Sobolev, Luís Carlos

6. Curricular Unit

Advanced Physics Topics

Module

Scanning Probe Microscopy and Electron Microscopy Techniques (SMTEM)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Andrei Kholkin and Augusto Barros Lopes (U. Aveiro)

Summary of Contents

This module is designed to provide a broad view of the principles and fundamentals of different microscopy techniques, namely scanning probe microscopy and electron microscopy.

Scanning microscopy

Survey of SPM methods and their comparison with other microscopic techniques
STM and AFM instrumentation
Scanning Tunnelling Microscopy and applications
Forces at the nanoscale and contact AFM
Contact vs. non-contact and tapping AFM.
Electrostatic and Magnetic Force Microscopy
Kelvin Force Probe Microscopy
Piezoresponse Force Microscopy and nanoscale characterization of ferroelectrics.
Scanning Near-field Optical Microscopy
Nanoindentation
Scanning Spreading Resistance Microscopy
AFM demonstration and practical classes

2. Electron microscopy

The electron microscopy as a materials characterization technique

The depth of field and the resolution limit of the optical microscope

Advantages of using electrons

The basic constitution and working principles of the scanning electron microscope (SEM), the transmission electron microscope (TEM) and the scanning transmission electron microscope (STEM).

Sample preparation for SEM and TEM

The Energy Dispersive Spectroscopy (EDS).

SEM and EDS practical demonstration

The interaction volume. Influence of the atomic number, thickness, electron beam energy and sample tilting.

SEM observation modes. Secondary and backscattered electron image modes.

TEM Image and diffraction modes

TEM Contrast. Mass-Thickness contrast, diffraction contrast (bright and dark field image modes) and phase contrast

TEM practical demonstration

Evaluation

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

Jury

Andrei Kholkin and Augusto Barros Lopes, João Ventura.

7. 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, José Carmelo

8. Curricular Unit

Advanced Physics Topics 1

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

9. 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

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Jury

Mário Ferreira, Manuel Marques, Helder Crespo

10. Curricular Unit

Advanced Physics Topics

Module

Quantum information and applications

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Ariel Guerreiro, U. Porto

Summary of Contents

1.Introduction to quantum information theory
Goals: introduce the fundamental notions and provide a bird eye view of the course and of the state of the art of the applications of quantum information theory.
1.1. History of information theory and applications
1.2. A statistical approach to information
1.3. Review of principles and formalism of quantum physic
1.4. Representation theory and informational problems in quantum physics
2. Resources of quantum information systems
Goals: discuss and introduce the two may quantum ingredients of many quantum information applications: quantum correlations (including entanglement) and decoherence (as a limiting physical process).
2.1. Quantum nonlocality and entanglement
2.2. The no-cloning theorem
2.3. Decoherence in quantum systems and information loss
2.4. Examples: quantum teleportation and high temperature entanglement in opto-mechanical systems.
MAP-fis Physics Doctoral Program – mapfis@map.edu.pt – http://www.map.edu.pt/fis
Departamento de Física e Astronomia,Faculdade de Ciências da Universidade do Porto
4169-007 Porto Portugal - Tel: +351 2204023933. Detection and measurements
Goal: present the key aspects behind the problem of extracting information from quantum systems.
3.1. Detectors, fluctuations and dark noise
3.2. von Neumann measurement theory
3.3. CP-maps and POVM

3.4. Examples: detection of gravitational waves and quantum sensing.
4. Quantum communications and cryptography
Goals: analyse the limitations and application of quantum systems for communications.
3.1. Communications based on quantum processes
4.2. Quantum cryptography and quantum key distribution
4.3. Quantum networks
4.4. Example: the BB84 protocol.
5. Quantum computation
Goals: understand how quantum physical processes can be used to manipulate information, i.e. quantum computation.
5.1 From the Feynman approach to quantum computing to the universal quantum computers
5.2. Modern implementations of quantum computers
5.3. Quantum operations and quantum logic gates
5.4. Examples: analyses some simple quantum algorithms.
6. Quantum simulations
Goals: discuss a physical application of quantum systems and quantum computing in particular.
6.1. The role of quantum computation in physics
6.2. Analogue simulation using quantum systems
6.3. Quantum simulation using quantum computers
6.4. Examples

Evaluation

The students are evaluated via a research report on a topic of quantum information theory and applications

Jury

Ariel Guerreiro, João Lopes dos Santos; Ricardo Dias

11. Curricular Unit

Advanced Physics Topics

Module

Graphene plasmonics (GP)

Type

Lecture courseContact 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, João Lopes do Santos

12. 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

13. Curricular Unit

Advanced Physics Topics

Module

Introduction to nano-optics

Type

Tutorial: Reading and Study assignment

Contact hours

18

Professor/Researcher in charge

Manuel Joaquim Marques, Orlando Frazão

Summary of Contents

1. Introduction

Maxwell´s equations and light propagation in free space. Wave equation. Electromagnetic waves. Reflection and refraction. Fresnel laws of reflection and transmission. Basic notions concerning guided propagation and waveguides.

2. Light propagation in planar waveguides

TE and TM guided modes in parallel plane guides. Guided modes and total reflection. Dispersion relation. Propagation cutoff, limits of high and low frequency, number of guided modes. Normalized parameters and normalized dispersion relation of TE and TM modes. Intermodal and intramodal dispersion. Guided power and power confinement. Radiated power. (Characterization of planar guides with a prism). Orthogonality and normalization of the modes. Expansion of an arbitrary field in normal modes. Reference the loss-gain and surface plasmons. Three-dimensional waveguides. Method of effective indices. (MMI devices; Radiation from a three-dimensional waveguide; Gaussian approximation to the fundamental mode).

3. Light propagation in optical fibers

Propagation in fibers with step index profile (SI). HE, EH, TE and TM modes. Dispersion relation. Propagation cutoff. Normalized parameters. Dispersion. Groups of modes in the limit of weak guidance; LP pseudo modes. Single mode operation. Guided power and modal power confinement. Leaky modes. Radiated power. Dispersion in single mode fibers. Control of dispersion, (and US, DS and DF fibers. Modal diameter (MFD) and equivalent step index profile (ESI)). Polarization dispersion and birefringence in optical fibers e microstructured fiber. Theoretical analysis of nanofiber confinement properties when the geometry is much reduced when compared with the wavelength.

4. Coupled mode theory

Lorentz reciprocity theorem, orthogonality of modes, expansion of an arbitrary field in eigenmodes of the unperturbed guide. System of coupled equations in the modal amplitudes; coupling coefficients. Directional coupler; phase synchronism; power transfer; spectral behavior. Optical tunable filter and optical switch. Analysis of directional coupling in terms of super modes of the structure; arrays of coupled guides. Contra directional coupling in a guide with a periodic grating; phase synchronism; reflection coefficient; spectral response of the reflector.

5. Light emission and light interactions in nanoscale environments

Quantum electrodynamics (QED) applied in a phenomenological way to study light interactions in nanoscale environments. Multipole expansion applied to the classical particle-field Hamiltonian. The radiating electric dipole. Spontaneous decay. Classical lifetimes and decay rates. Dipole-Dipole interaction. Delocalized excitations. Entanglement.

6. Nano-optics Applications

Forces in optical near-field, Maxwell´s stress tensor and radiation pressure. Dielectric probes. Tapered optical fibers and tips. Light propagation in a conical dielectric probe. Power transmission. Near-field distribution. Enhancement of transmission and directionality. Optical properties in metals. Surface plasmon polaritons at plane interfaces. Surface plasmons in nano-optics. Two and three dimensional periodic structures. Photonic crystals with a square lattice. Band structure for photonic crystals with square lattice. Waveguides with photonic crystals. Photonic crystal fibers.

References

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Evaluation

The evaluation will assess to write a report and also may be published in a book chapter. The student still has to present his work in an oral presentation.

Juri

Manuel J. Marques, Orlando Frazão, Mário Ferreira

14. Curricular Unit

Advanced Physics Topics

Module

Biomedical Signal and Image Analysis

Type

Lecture course

Contact hours: 18

Professor/Researcher in charge

Ana Paula Rocha, André Marçal

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.

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

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Jury

Ana Paula Rocha, André Marçal

15. 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.

References

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

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Jury

Carla Carmelo Rosa, J. Agostinho Moreira,

16. 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

17. Curricular Unit

Advanced Physics Topics

Module

Data Analysis in Particle Physics

Type

Tutorial

Contact hours

18h

Professors/Researchers 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.

During the tutorial, the following topics will be covered:

1) Monte Carlo Simulation
    1.1) Event generation and the use of Madgraph
2) Analysis tools
    2.1) Data analysis at the LHC
        2.1.1) Basic concepts
        2.1.2) C++ and ROOT
        2.1.3) Madanalysis
        2.1.4) Multivariate analysis techniques and the use of TMVA
3) Limit setting in searches for new physics phenomena

The tutorial will consist on a set of different exercises, designed to illustrate in an hands-on way, the use of the different tools and techniques, with the final goal being the development of a data analysis project by each student.

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, Antonio Onofre

18. Curricular Unit

Advanced Physics Topics

Module

Experimental Particle and Astroparticle Physics, Advanced Analysis Methods, Top quark physics, Standard model and beyond (EPAP)

Type

Tutorial

Contact hours

18 TP

Professor/Researcher in charge

Antonio Onofre

Summary of Contents

This course involves the study of advanced analysis methods for PhD students within the field of Particle Physics. Following a theoretical revision on the current status of top quark physics, several applications are discussed. During the course, students are expected to be able to perform simple theoretical calculations related to top quark physics and explore the physics of its decay. The interplay between the top quark physics and the recently discovered Higgs boson is exercised as an application. Students are expected to analyse dedicated samples of ttH Monte Carlo events (with an hands-on approach). A production cross section limit at the LHC is extracted using advanced statistical tools.

Evaluation

Students are expected to follow at least 2/3 of the lectures, in both topologies i.e., Theoretical (T) and Theoretical-Pratical (TP). 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:

Attendance	10%
Individual/Team work	35%
Quizzes	25%
Final Exam	30%

Jury

Antonio Onofre, Nuno Castro, Antonio Morais

19. Curricular Unit

Advanced Physics Topics

Module

Correlations Effects in Low-Dimensional Materials and Systems (CELDM)

Type

Tutorial

Contact hours

18

Professor/Researcher in charge

José Carmelo, U. Minho

Summary of Contents

Why are the effects of many-body interactions more important in lower dimensions?
The Fermi liquid versus non-perturbative low-dimensional electronic problems.
The Luttinger liquid and beyond it.
Solvable 1D electronic models.
Different properties of integrable and non-integrable 1D quantum problems.

Evaluation

Written report with oral defense

Jury

José Carmelo, João Lopes dos Santos, Antonio Luís Ferreira