Advanced Topics In Physics I: 2016-2017

This curricular unit is composed of several modules described below. Each student must choose a total of six modules to complete this unit.
Timetables will be arranged after students choices are known. Modules take usually 5/6 weeks with 3/4 contact hours per week.

Modules

1. Experimental Particle and Astroparticle Physics (EXPAP), Antonio Onofre, U. Minho
2. Data Analysis in Particle Physics (DAPP), Nuno Castro, U. Porto/U. Minho
3. Correlations Effects in Low-Dimensional Materials and Systems (CELDM), Jose Carmelo, U. Minho
4. Dark Energy, Dark Matter & Gravity (DEDMG), Orfeu Bertolami, U. Porto.
5. Lasers, optics and photonics (LOP), Mario Ferreira, U. Aveiro,
6. Graphene plasmonics (GP), Yuli Bludov (U. Minho)
7. Advanced Materials Preparation and Characterization (AMPC), Bernardo Almeida, U Minho.
8. Nanomagnetism (NM), J E Araújo, U. Porto, Vitor Amaral, U. Aveiro.
9. Clean Room and Micro-fabrication (CRMF), Paulo Marques, João Oliveira Ventura, U. Porto
10. Group Theory and applications to Condensed Matter Phyiscs (GTACMP), Joaquim Agostinho Moreira, U. Porto
11. The Physics of Electronic Materials and Devices (PEMD), Pedro Alpuim,. U. Minho
12. Computational Physics (CP), Antonio Luis Ferreira, U. Aveiro, João Viana U. Porto.
13. Spectroscopic techniques for the characterization of materials (STCM), Luis Carlos, Rute André e N. Sobolev, U. Aveiro
14. Scanning Microscopy Techniques and Electronic Microscopy (SMT), Andrei Kholkine and Augusto Barros Lopes (U. Aveiro)
15. Black Holes (BH), Carlos Herdeiro, U. Aveiro
16. Introduction to gauge/gravity duality (IGGD), Dimitri Zoakos (CFP- U Porto);
17. Introduction to nano-optics (INO), Orlando Frazão, Manuel J. Marques (U.Porto)
18. Biomedical Signal and Image Analysis (BSIA), Ana Paula Rocha, André Marçal, U. Porto
19. Biophotonics: sensing and imaging (BPSI) Carla Carmelo Rosa, J. Agostinho Moreira, U,.

Porto

20. Computational Methods in Medical Physics (CMMP) Alessandro Esposito
21. Effective Doses in Radiology (EDR) Sandra Sarmento, IPO-Porto
22. Internal Dosimetry in Nuclear Medicine (IDNM), João António Miranda dos Santos, IPO-Porto)
23. Nanomedicine: Science and Applications (André Miguel Trindade Pereira)
24. Nuclear Medicine: SPECT, PET and radionuclides production, (João Veloso)
25. Problems in Many-Body theory (João Lopes dos Santos)
26. Statistical Methods in High Energy Physics, Nuno Castro
27. Topics in General Relativity and Cosmology , Jorge Páramos (U. Porto)

1. Curricular Unit

Advanced Physics Topics 1

Module

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

Type

Lecture course

Contact hours

20 (12 T, 8 p)

Professor/Researcher in charge

Antonio Onofre, Nuno Castro, U. Minho

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, Orfeu Bertolami

2. Curricular Unit

Advanced Physics Topics 1

Module

Data Analysis in Particle Physics

Type

Lecture Coursework

Contact hours

18 (8 T, 10 P)

Professor/Researcher in charge

Nuno Castro, U. Porto and U. Minho

Summary of Contents

With the data collected during the first operation phase of the Large Hadron Collider (LHC) at CERN, the Standard Model of Particle Physics and many new physics models beyond it were tested at an unprecedented energy at colliders. This required the use of advanced statistical techniques capable of dealing with the huge amount of collected data. This course aims at providing an overview of the main experimental tests of the Standard Model at the LHC and previous colliders, and to provide a comprehensive and practical approach to the various analysis methods typically encountered in particle physics. Searches for new physics beyond the Standard Model will also be discussed.

The course is divided in theoretical and practical lectures. In the theoretical lectures (8 hours) the fundamental concepts and techniques are introduced while in the practical lectures (10 hours) important tools for simulation and data analysis will be exercised with realistic use cases in the context of different analysis relevant for the LHC physics program.

Topics of the theory lectures:
1. The Standard Model of Particle Physics
2. Data Analysis in High Energy Physics
3. Searches and Precision Measurements at the LHC

Topics of the practical lectures:
1. Introduction to Monte Carlo Simulation
2. Analysis tools
2.1 ROOT
2.2 Madgraph
2.3 Madanalysis
2.4 TMVA

Evaluation

1. Students are expected to follow at least 2/3 of the theoretical and practical lectures.

2. The evaluation will be done based on the attendance and participation in discussions as well as individual and team works.
The weight of the different components in the final grade is as follows:
Participation in class 10%
Individual work and exercises 25%
Final work (presentation) 65%

Bibliography

- The Standard Model and Beyond, P. Langacker, CRC Press (2011).
- Introduction to Particle and Astroparticle Physics – Questions to the Universe, A. De Angelis and M. Pimenta, Springer (2015).
- Data Analysis in High Energy Physics, O. Behnke, K. Kroeninger, G. Schott and T. Schoener-Sadenius, Wiley-VCH Verlag (2013).
- Workshop on Confidence Limits, F. James, CERN-2000-005 (2000).
- ROOT – Data Analysis Framework, http://root.cern.ch/drupal
- Madgraph 5, http://madgraph.hep.uiuc.edu
- Madanalysis, https://launchpad.net/madanalysis5
- TMVA – Toolkit for Multivariate Data Analysis, A. Hoeker, CERN-OPEN-2007-007 (2007).

Jury

Nuno Castro, Antonio Onofre, João Veloso

3. Curricular Unit

Advanced Physics Topics 1

Module

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

Type

Lecture course

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

4. Curricular Unit

Advanced Physics Topics 1

Module

Dark Energy, Dark Matter & Gravity (DEDMG)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Orfeu Bertolami

Summary of Contents

Recent observational evidence arising from the cosmic microwave background radiation (CMB), from type Ia supernovae (SNe-Ia), from baryon acoustic oscillations (BAO), etc, indicate that the expansion of the Universe is accelerating, and that matter that can be observed through the electromagnetic radiation cannot account for the formation of galaxies, cluster and superclusters of galaxies. These observations suggest that, on large scales, the dynamics of the Universe is dominated by a smooth uniformly distributed form of energy, dark energy, and that structure formation requires a substantial amount of a new form of matter, dark matter. The nature and the characterization of these dark components are central issues in contemporary cosmology. Of course, a relevant related question is whether the observations can be accounted by alternative theories of gravity. Thus, in these lectures, observational and theoretical ideas and proposals to unravel these open questions will be discussed.

References

Dynamics of dark energy
E. Copeland, M. Sami, S. Tsujikawa. Mar 2006 - 84 pages
Int.J.Mod.Phys. D15 (2006) 1753-1936
DOI: 10.1142/S021827180600942X
e-Print: hep-th/0603057
Astrophysical and cosmological probes of dark matter
M. Roos. Aug 2012. 39 pp.
e-Print: arXiv:1208.3662 [astro-ph.CO]
Dark Matter: The evidence from astronomy, astrophysics and cosmology Matts Roos. Jan 2010. 25 pp. e-Print: arXiv:1001.0316 [astro-ph.CO]

Jury

Orfeu Bertolami, João Rosa, Filipe Mena

5. Curricular Unit

Curricular Unit

Advanced Physics Topics 1

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

6. Curricular Unit

Advanced Physics Topics 1

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, João Lopes do Santos

7. Curricular Unit

Advanced Physics Topics 1

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

8. Curricular Unit

Advanced Physics Topics 1

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

9. Curricular Unit

Advanced Physics Topics 1

Module

Clean Room and Micro-fabrication (CRMF)

Type

Practical instruction

Contact hours

18

Professor/Researcher in charge

João Oliveira 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

10. Curricular Unit

Advanced Physics Topics 1

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 $k \neq 0$. 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

11. Curricular Unit

Advanced Physics Topics 1

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, Joaquim Agostinho, Joaquim Leitão

12 Curricular Unit

Advanced Physics Topics 1

Module

Computational Physics (CP)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Antonio Luis Ferreira, U. Aveiro, J Viana Lopes , U. Porto

Summary of Contents

Part 1 (9 hours)
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.

Part 2
Introduction to the Kernel Polynomial Method for disordered electronic
Application to Physical Problems (typical Hamiltonians, observables).
Numerical implementation.
Parallelization.

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
Parallel Programming in C with MPI and OpenMP", Michel J. Quinn, 2004, McGraw-Hill.
Parallel Programming with MPI, Peter S. Pacheco, 1997, Morgan Kaufmann.
The Kernel Polynomial method., Alexander Weiβe, et al. Rev. Mod. Phys,. **78**, 275, 2006

Evaluation

Exam with computational exercises (part1); written report with oral defense (part2).

Jury

António Luís Ferreira, Manuel Barroso, Carla Rosa

13 Curricular Unit

Advanced Physics Topics 1

Module

Spectroscopic techniques for the characterization of materials (STCM)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Luis Carlos, 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; EPR

Evaluation

Written Test (3h).

Juri

Luís Carlos, Florinda Costa; João Pedro Araújo

8. Curricular Unit

Advanced Physics Topics 1

Module

Scanning Microscopy Techniques (SMT) and Electronic Microscopy (MGTEM)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Andrei Kholkine 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 microscopy and electron microscopy.

Scanning microscopy
Survey of STM and 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. Electronic 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’).

15. Curricular Unit

Advanced Physics Topics 1

Module

Black Holes (BH)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Carlos Herdeiro, U. Aveiro,

Summary of Contents

Black holes are thought to play a central role in various astrophysical processes. Moreover, over the last three decades, the study of black hole solutions, their classical and quantum properties and their interactions, has become an increasingly central topic in high energy physics and mathematical/physics models.

This is an introductory course on black hole physics covering the Schwarzschid, Reissner-Nordstrom and Kerr black holes, their physical and mathematical properties. The course assumes basic knowledge of General Relativity and will end with an overview of current research directions in black hole physics.

Course synopsis:

1 - Revision
1.1 Some facts about Newtonian gravity
1.2 Some facts about General Relativity

2 – Schwarzschild black holes
2.1 Derivation of the solution
2.2 Properties of the solution
2.2.1 Geometrical properties
2.2.2 Classical test motions
2.2.3 Black holes and white holes

3 - Reissner-Nordstrom-(Anti)-De-Sitter black holes
3.1 Derivation of the solution

3.2 Properties of the solution
3.2.1 Geometrical properties
3.2.2 Charged geodesics and the Majumdar-Papapetrou solution
3.3 Carter Penrose diagrams

4 - Kerr black holes
4.1 Motivation and presentation of the solution in various coordinate systems
4.2 Geometrical properties
4.3 Ergo-sphere, ergo-region and physical consequences

5 - A summary of important results in black hole physics
5.1 Uniqueness (and no-hair) theorems
5.2 Laws of black hole theormodynamics

6 - Overview of current research directions in black hole physics
6.1 Astrophysics
6.2 High energy physics
6.3 Mathematical physics

Evaluation

- Oral presentation of a research paper
- Take home written exam

Juri

Carlos Herdeiro, Orfeu Bertolami

16. Curricular Unit

Advanced Physics Topics 1

Module

Introduction to gauge/gravity duality

Type

Lectures and Reading and Study assignment

Contact hours

18

Professor/Researcher in charge

Dimitri Zoakos (U. Porto)

Summary of Contents

1. Conformal field theory review: conformal transformations, local operators, ward identities, state-operator map, operator product expansion, conformal bootstrap, embedding space formalism, large N factorization.

2. Anti-de Sitter spacetime: particle dynamics in AdS, quantum field theory on AdS, state-operator map, generating function, gravity with AdS boundary conditions.

3. The AdS/CFT correspondence: quantum gravity as CFT, string theory, finite temperature, applications, open problems.

References

J. McGreevy, "Holographic duality with a view toward many-body physics," Adv.High Energy Phys. 2010 (2010) 723105, arXiv:0909.0518 [hep-th].
S. A. Hartnoll, "Lectures on holographic methods for condensed matter physics," Class.Quant.Grav. 26 (2009) 224002, arXiv:0903.3246 [hep-th].
O. Aharony, S. S. Gubser, J. M. Maldacena, H. Ooguri, and Y. Oz, "Large N field theories, string theory and gravity," Phys.Rept. 323 (2000) 183–386, arXiv:hep-th/9905111 [hep-th].
E. D'Hoker and D. Z. Freedman, "Supersymmetric gauge theories and the AdS / CFT correspondence," arXiv:hep-th/0201253 [hep-th].

Evaluation

Problems solved and presented by the students during the course.

Juri

Miguel Costa, Dimitri Zoakos

17. Curricular Unit

Advanced Physics Topics 1

Module

Introduction to nano-optics

Type

Tutorial: Reading and Study assignment

Contact hours

18

Professor/Researcher in charge

Orlando José Reis Frazão, Manuel Joaquim Marques

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

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

Orlando Frazão, Manuel J. Marques, Mário Ferreira

18. Curricular Unit
Advanced Physics Topics 1

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

19. Curricular Unit
Advanced Physics Topics 1

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

1. *Markolf H. Niemz; Laser-tissue interactions. ISBN: 978-3-540-72191-8, 2007.*
2. *R. Splinter; An introduction to biomedical optics. ISBN: 0-7503-0938-5, 2007.*
3. *Lihong V. Wang; Biomedical optics. ISBN: 978-0-471-74304-0, 2007.*
4. *Barry R. Masters; Confocal microscopy and multiphoton excitation microscopy. ISBN: 978-0-8194-6118-6, 2006.*
5. *Hans-Ulrich and Bing Yan (Eds). Infrared and Raman Spectroscopy of Biological Materials. Practical Spectroscopy Series. ISBN 0-8247-0409-6, 2001.*
6. *Katrin Kneipp, martin Moskovits and Harald Kneipp. Surface-Enhanced Raman Scattering, Physics and Applications. ISBN: 978-3-540-33566-5, 2006.*
7. *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).*
8. *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).*

20. Curricular Unit
Advanced Physics Topics 1

Module
Computational Methods in Medical Physics

Type
Lecture course

Contact hours
18

Professor/Researcher in charge
Alessandro Esposito

Summary of Contents

- The Monte Carlo (MC) approach as numerical solution to complex problem
- MC applications in Medical Physics
- MC simulation of radiation transport and radiation/matter interaction
- The statistics as a main problem in MC
- Variance reduction methods: Phase Space, Beam Splitting etc…
- Examples of MC code in use, specifically for Radiation Therapy
- Basics of coding
- Calculation and representation of dose in phantom or patient,
- Steps for construction of Linear Accelerator (LINAC) geometrical and physical models
- LINAC model validation
- Strategies and examples toward the 4D MC in Medical Physics
- Tools for data analysis

References

9. *Seco, J., & Verhaegen, F. (Eds.). (2013). Monte Carlo techniques in radiation therapy. CRC Press.*
10. *Bielajew, A. F. (2001). Fundamentals of the Monte Carlo method for neutral and charged particle transport. The University of Michigan.*
11. *Team, M. C. (2003). MCNP–a general Monte Carlo N-particle transport code, version 5. Book MCNP-A General*
12. *GEANT4 user manual*
13. *M. Rodriguez, J. Sempau and L. Brualla, PRIMO: A graphical environment for the Monte Carlo simulation of Varian and Elekta linacs, Strahlenther. Onkol. 189 (2013) 881-886.*

21. Curricular Unit
Advanced Physics Topics 1

Module
Effective Doses in Radiology

Type
Tutorial: Reading and Study assignment

Contact hours
18

Professor/Researcher in charge
Sandra Sarmento, IPO-Porto

Summary of Contents
Biological aspects of radiological protection: stochastic and deterministic effects. Quantities used in radiological protection: dose quantities, tissue weighting factors, effective dose.
Uncertainties in calculations of effective dose. Limitations and appropriate uses of effective dose.
Examples of risk assessment for mammography screening.
Calculation of effective doses in computed tomography.
Estimating Population Doses from Medical X-Ray Procedures.

Evaluation

References

The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007; 37
Martin CJ. *Effective dose: how should it be applied to medical exposures?* Br J Radiol 2007;80:639-647
Martin CJ. *The application of effective dose to medical exposures*. Radiat Prot Dosimetry 2008;128:1-4
Sechopoulos I, Suryanarayanan S, Vedantham S, D'Orsi CJ, Karellas A. *Radiation Dose to Organs and Tissues from Mammography : Monte Carlo and Phantom study*. Radiology 2008;246:434-443
Shrimpton PC, Jansen Jan TM, Harrison JD. *Updated estimates of typical effective doses for common CT examinations in the UK following the 2011 national review*. Br J Radiol 2016;89:20150346
Tsalafoutas IA, Thalassinou S, Efstathopoulos, EP. A *Comprehensive Method for Calculating Patient Effective Dose and Other Dosimetric Quantities From CT DICOM Images* AJR 2012;199:133–141
Radiation protection n° 154 European Guidance on Estimating Population Doses from Medical X-Ray Procedures European Commission 2008

Jury
Sandra Sarmento

22. Curricular Unit
Advanced Physics Topics 1

Module
Internal Dosimetry in Nuclear Medicine

Type
Tutorial: Reading and Study assignment

Contact hours
18

Professor/Researcher in charge
João António Miranda dos Santos, IPO-Porto

Summary of Contents
Nuclear Medicine Principles and Radiopharmaceuticals
Methods of Nuclear Medicine Radiation Dosimetry
MIRD and ICRP schemas
Anthropomorphic whole-body phantoms
Biodistribution
Patient-specific Radionuclide therapy planning

Evaluation

References
The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4), 2007
Radiation Dose to Patients from Radiopharmaceuticals. ICRP Publication 53. Ann. ICRP 18 (1-4), 1988
Nuclear Medicine Radiation Dosimetry – Advanced theoretical principles, Brian J. Parland, Springer, 2010
Fundamentals of Nuclear Medicine Dosimetry, Michael G. Stabin, Springer, 2008

Jury

João António Miranda dos Santos, IPO-Porto

23. Curricular Unit
Advanced Physics Topics 1
Module
Nanomedicine: Science and Applications
Type
Lecture course
Contact hours
18
Professor/Researcher 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:

i) 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.

Evalauation

References

[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-Fe_2O_3@SiO_2 superparamagnetic nanoparticles”, Journal of Applied Physics, 109 (2011) 114319.
[3] C. Pereira, A.M. Pereira, M. Rocha, C. Freire, C.F.G.C. Geraldes, “Architectured design of superparamagnetic Fe_3O_4 nanoparticles for application as MRI contrast agents: mastering size and magnetism for enhanced relaxivity”, Journal of Materials Chemistry B, 3 (2015) 6261–6273.

Jury

André Miguel Trindade Pereira

24. Curricular Unit
Advanced Physics Topics 1

Module
Nuclear Medicine: SPECT, PET and radionuclides production
Type

Contact hours
18

Professor/Researcher in charge
João Veloso (U . Aveiro)

Summary of Contents
Address the thematics associated with Nuclear Imaging, focusing on the physics and the related state-of-the-art techniques and instrumentation and radionuclides production. Depending of the students background, an introduction of the physical aspects associated with the interaction of ionizing radiation with matter, will be done

References
J Bushberg et al, *The Essential physics of Medical Imaging, third edition*, Lippincott Williams & Wilkins, 2012.
W R Hendee, E R Ritenour, *Medical Imaging Physics, Wiley*
recent publications from journals related with the thematics of the course.

25.Curricular Unit

Advanced Physics Topics 1

Module

Problems in Many-Body theory

Type

Tutorial

Contact hours

18

Professor/Researcher in charge

João Lopes dos Santos (CFP-U. Porto)

Summary of Contents

1. Anderson Model: Application to Graphene

To study Anderson's model of formation of local moments in metals [1]. To reproduce the results of [2] that applies Anderson's model to graphene.

2. **Green's Functions for electrons in a disorderd Potential.**

To calculate diagrammatically the conductivity of an impure metal in the weak disorder limit [3]

References

[1]R Jishi, *Feynman Diagrams in Condensed Matter Theory*: Chapters 6 and 7

[2] B. Uchoa et al. Localized magnetic states in graphene, PHYSICAL REVIEW LETTERS **101,** 026805   (2008)

[3] Green's Functions for Solid State Physicists , by S Doniach , E. Sondheimer, Chapter 5.

Evaluation

Written reports of the calculations.
Jury
João Lopes dos Santos; Nuno Peres; R G. Dias

26. Curricular Unit

Advanced Physics Topics 1

Module

Statistical Methods in High Energy Physics

Type

Tutorial

Contact hours

18

Professor/Researcher in charge

Nuno Castro

Summary of Contents

A key element of the physics program of the modern collider experiments is the search for phenomena beyond the Standard Model of Particle Physics. In this context, mastering the statistical techniques required to interpret the experimental results is absolutely necessary for a successful career in this field.

Um elemento importante do programa de física das experiências de colisionadores de partículas é a pesquisa de fenómenos não previstos no Modelo Padrão. Neste contexto, o domínio de técnicas estatísticas que permitam interpretar os resultados experimentais obtidos reveste-se de enorme importância.

In this tutorial the following topics will be covered:

1) Advanced statistical methods commonly used in High Energy experiments

2) Statistical inference

3) Hypothesis testing

4) Confidence intervals

5) The CLs method

6) Fits to experimental data

7) Nuisance parameters and systematic uncertainties

Evaluation

Informal weekly discussions (20%); final presentation on the application of the methods learn during the tutorial to a concrete problem (40%) and corresponding discussion with the jury (40%).

Jury

Nuno Castro, Juan Pedro Araque, António Onofre

27. Curricular Unit

Advanced Physics Topics 1

Module

Tópicos de Relatividade Geral e Cosmologia

Type

Tutorial

Contact hours

18 h

Professor/Researcher in charge

Jorge Páramos

Summary of Contents

- Inflationary models

- Gravitational Waves

- Cosmic Background Radiation

- Topological Defects

- Mathematical aspects of General Relativity

Evaluation

- Written essay and public presentation

Jury

Jorge Páramos, Orfeu Bertolami and João Rosa