Advanced Topics In Physics

2023-2024

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 (UM)
2. Black holes: theory and recent observations (BH) Carlos Herdeiro (UA)
3. Climate variability and change **(CVC)** Alfredo Rocha (UA)
4. Computational Physics **(CP)** António Luís Ferreira, UA, J Pedro Coutinho (UA)
5. Contemporary Optics: Understanding Concepts of Modern Optical Applications from Sensing to Computing (**CO**) Nuno Azevedo Silva (UP)
6. Data Analysis in Particle Physics **(DAPP)** Nuno Castro (UM)
7. Exotic compact objects: selected theory and phenomenology **(ECO)** Eugen Radu, Guilherme Raposo, Hector Olivares
8. Experimental Particle and Astroparticle Physics, Advanced Analysis Methods, Top quark physics, Standard model and beyond **(EPAP)** Nuno Castro (UM)
9. Graphene Plasmonics **(GP)** Yuli Bludov (UM)
10. Group Theory and applications to Condensed Matter Physics **(GTACMP)** J. Agostinho Moreira (UP)
11. Large Infrastructures Characterization Techn. for Cond. Matter Physics **(LICTCMP)** Rui Vilarinho, Joaquim Agostinho Moreira (UP)
12. Laser, Optics and Photonics **(LOP)**
13. Numerical simulation of the atmosphere and ocean **(NSAO)** José Fortes
14. Optical fiber-based components and devices (**OFCD)** Marta Ferreira (UA)
15. Quantum Computing **(QC)** Duarte Magano (UP)
16. The Weather Research and Forecasting model **(WRF)** David Carvalho
17. Introduction to Topological Matter (**ITM**) Eduardo Castro (UP)
18. Standard Model I António Morais (UM)
19. Standard Model II António Morais (UM)

Jury Panels

1. AMPC: Bernardo Almeida, João Ventura
2. BH: Carlos Herdeiro, Pedro V. P. Cunha and Miguel Zilhão
3. CVC: Alfredo Rocha, João Dias, Jesus Dubert
4. CP: António Luís Ferreira, J Pedro Coutinho
5. CO: Nuno Azevedo Silva, Ariel Guerreiro
6. DAPP: Nuno Castro, António Morais, Raul Sarmento
7. ECO: Eugen Radu, Guilherme Raposo, Hector Olivares
8. EPAP: Nuno Castro, António Morais, Raul Sarmento
9. GP: Yuli Bludov, Nuno Peres
10. GTACMP: Joaquim Agostinho Moreira, Nuno Peres
11. LICTCMP: Rui Vilarinho, Joaquim Agostinho Moreira
12. LOP: Mário Ferreira, Manuel Marques
13. NSAO: José Fortes, João Dias, Jesus Dubert
14. OFCD: Marta Sofia dos Anjos Ferreira, Manuel Marques
15. Quantum Computing: Duarte Magano, Ariel Guerreiro, Maria de Fátima Mota
16. WTF The Weather Research and Forecasting model: David Carvalho, João Dias, Jesus Dubert
17. ITM: Eduardo Castro, Victor Pereira
18. SMI: António Morais, António Onofre, Nuno Castro
19. SMII: António Morais, António Onofre, Nuno Castro

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

Module

Black Holes: theory and recent observations (BH)

Type

Lecture Course

Contact hours

18

Professor/Researcher in charge

Carlos Herdeiro

Summary of Contents

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

Bibliography

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;

The Astrophysical Journal Letters, 875, nº1 https://iopscience.iop.org/article/10.3847/2041-8213/ab0ec7;

https://arxiv.org/abs/gr-qc/9707012; https://arxiv.org/abs/1504.08209; https://arxiv.org/abs/1801.00860; https://arxiv.org/pdf/gr-qc/9506086; https://arxiv.org/abs/gr-qc/0507014; https://arxiv.org/pdf/1410.7775.pdf; https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.061102; https://arxiv.org/abs/2009.05376

Evaluation

Problem sets and paper presentation.

Jury

Carlos Herdeiro, Pedro V. P. Cunha and Miguel Zilhão

Module

Climate variability and change (CVC)

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.

Bibliography

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

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 (9 hours): 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"

Bibliography

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

Module

Contemporary Optics: Understanding Concepts of Modern Optical Applications from Sensing to Computing

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Nuno Azevedo Silva

Summary of Contents

Each part comprises lecture and hands-on approaches with real optical systems, complemented with lab tours focusing on each topic.

Part 1(4 hours) Optical Sensors: Interferometers, designs and implementations; Plasmonic-based sensors: concepts, designs and applications; Spectroscopy techniques: from single-point to imaging analysis; Quantum-enhanced interferometry.
Part 2(4 hours) Optical Computers: the neuromorphic paradigm; possible architectures: from diffractive neural networks, extreme learning machines. Wavefront shaping technologies: spatial light modulators.
Part 3(4 hours) Analogue Simulators: using optical systems to probe and explore inaccessible theoretical physical systems, from quantum to cosmological effects.
Part 4 (4 hours) Data processing tools: challenges of building robust solutions with machine learning concepts for real world applications based on optical sensors;

References

Pierangeli, Davide, Giulia Marcucci, and Claudio Conti. "Photonic extreme learning machine by free-space optical propagation." Photonics Research 9.8 (2021): 1446-1454.

Lin, Xing, et al. "All-optical machine learning using diffractive deep neural networks." Science 361.6406 (2018): 1004-1008.

Carusotto, Iacopo. "Superfluid light in bulk nonlinear media." Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 470.2169 (2014): 20140320.

Evaluation

Report on a specific topic, adjusted to student's choice

Jury

Nuno Azevedo Silva, Ariel Guerreiro

Module

Data Analysis in Particle Physics (DAPP)

Type

Tutorial

Contact hours

18

Professor/Researcher 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, Raul Sarmento

Module

Exotic compact objects: selected theory and phenomenology (ECO)

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Eugen Radu, Guilherme Raposo, Hector Olivares

Summary of Contents

Part 1: No hair theorems; solitons in field theory; Boson and Proca Stars: static, spinning and multi-component configurations; Black Holes with synchronized bosonic hair; Scalarized Black Holes: the Einstein-Maxwell-scalar and Einstein-Gauss-Bonnet-scalar cases
Part 2: Self-gravitating fluids. TOV equations. Beyond perfect fluids: Anisotropic and elastic stars; Gravitational-wave signatures of compact objects – tidal deformability and gravitational echoes
Part 3: Black holes and compact objects in astrophysics; Thin disks around black holes and boson stars; Thick disks around black holes and boson stars; Present status of observations

Bibliography

https://arxiv.org/abs/1403.2757; https://arxiv.org/abs/1504.08209; https://arxiv.org/abs/1711.02080; https://arxiv.org/abs/1806.05190;https://arxiv.org/abs/2211.01766; Y. Shnir, "Topological and Non-Topological Solitons in Scalar Field Theories", Cambridge University Press (2018), ISBN: 9781108555623 (https://www.cambridge.org/pt/universitypress/subjects/physics/theoretical-physics-and-mathematical-physics/topological-and-non-topological-solitons-scalar-field-theories?format=HB&isbn=9781108429917; Shapiro, S. L. and Teukolsky, S. A., "Black holes, white dwarfs, and neutron stars: The physics of compact objects" (1983); https://arxiv.org/abs/2105.06410; https://arxiv.org/abs/2307.03146; https://arxiv.org/abs/1811.07917; https://arxiv.org/abs/1806.05195; Meier, David L., Black Hole Astrophysics: The Engine Paradigm, Springer (2012), ISBN: 978-3-642-01935-7, ISBN 978-3-642-01936-4 (eBook); Novikov, I. D. and Thorne, K, S., Astrophysics of Black Holes, Black holes (Les astres occlus), p. 343-450; https://ui.adsabs.harvard.edu/abs/1973blho.conf..343N/abstract; Guzmán, F. S. ; Rueda-Becerril, J. M., Spherical boson stars as black hole mimickers, Physical Review D, vol. 80, Issue 8, id. 084023, arXiv:1009.1250; Olivares, H. et al., How to tell an accreting boson star from a black hole, MNRAS, Volume 497, Issue 1, pp.521-535, arXiv:1809.08682

Evaluation

Problem sets and paper presentation.

Jury

Eugen Radu, Guilherme Raposo, Hector Olivares

Module

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

Type

Tutorial

Contact hours

18 TP

Type

Tutorial

Professor/Researcher in charge

Nuno Castro

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%
Written report on the final work	45%
Oral presentation of the final work	45%

Jury

Nuno Castro, Raul Sarmento, António Morais

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 types 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

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 crys-tal
field.
Space groups in real space and in the reciprocal space. Symmetry of the k vectors and the group of the wave
vector. Representations of a space group. Little group and stars. Factor group analysis and the Γ point.
Points for k≠0. Compatibility relations.
Applications to lattice vibrations and electronic energy levels. Energy band models based on symmetry.
Spin-orbit coupling in solids and double groups and application to energy bands with spin.
Time reversal symmetry. The Magnetic Groups and their Co-representations. Properties of the magnetic point groups.

References

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

Jury
Joaquim Agostinho Moreira, ??

Module

Large Infrastructures Characterization Techniques for Condensed Matter Physics (LICTCMP)

Type

Lecture course with practical data analysis

Contact hours

18

Professor/Researcher in charge

Rui Vilarinho, Joaquim Agostinho Moreira

Summary of Contents

Nuclear and magnetic powder and single-crystal diffraction using synchrotron x-ray radiation or neutron beams from nuclear reactors / spallation sources, under challenging conditions (low to high temperature, high-pressure, high magnetic field, nanometric scale or fast timescales).

X-ray spectroscopies with synchrotron radiation: x-ray absorption spectroscopy (XAS), extended x-ray absorption fine structure (EXAFS), x-ray magnetic circular/linear dichroism (XMCD/XMLD).

Muon spin resonance spectroscopy (µSR) as local probes for magnetic materials.

Description of available techniques and tutorial in how/when to apply and write a scientific proposal, complemented with an online presentation from a beamline scientist and/or proposal evaluator.

Students will analyze data acquired (X-ray diffraction, neutron diffraction, EXAFS, XMCD and µSR) at large infrastructures using the respective beamline software.

Evaluation

Written Report or Written Report with oral presentation.

Bibliography

Synchrotron Radiation: Basics, Methods and Applications, Springer, ISBN 978-3-642-55315-8
Fundamentals of X-ray Absorption Fine Structure, Sakura Pascarelli, ESRF
Magnetism: A Synchrotron Radiation Approach, Lecture Notes in Physics, Springer, ISBN 3540332413
Muon Spectroscopy: An Introduction, Oxford University Press, ISBN 9780198858959

Jury

Rui Vilarinho, Joaquim Agostinho Moreira

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

Module

Numerical simulation of the atmosphere and ocean

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

Literature:

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. 251p.
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

Juri

José Fortes, João Dias, Jesus Dubert

Module
Quantum computing

Type
Lecture course

Contact hours
18

Professor/Researcher in charge
Duarte Magano, U. Porto

Summary of Contents
Part I: The principles of quantum computing
Classical and quantum bits; quantum logic gates; the quantum circuit model; the Solovay-Kitaev theorem; early quantum algorithms: Deutsch-Josza algorithm, Bernstein-Vazirani algorithm, Simon's algorithm.
Part II: How to build a quantum computer
Conditions for quantum computation; examples of possible physical realizations: harmonic oscillator quantum computer, photonic quantum computer, ion trap quantum computer; quantum error correction.
Part III: An overview of quantum complexity theory
Turing machines; the (strong) Church-Turing thesis; computational complexity; **P** vs **NP**; randomized computation; **BPP** vs **BQP**.
Part IV: Quantum algorithms
(A selection of:) Grover's algorithm; quantum simulation; phase estimation; continuous-time quantum walks; adiabatic quantum computing; Shor's algorithm; the hidden subgroup problem.
Part V: Quantum computing today
NISQ computers, variational quantum algorithms; the quantum supremacy experiments: randomized circuit sampling, boson sampling.

Bibliography
M. Nielsen, I. Chuang. Quantum Computation and Quantum Information: 10th Anniversary Edition (2010). Cambridge University Press.
S. Arora, B. Barak. Computational Complexity: A Modern Approach (2009). Cambridge University Press.
Ronald de Wolf. Quantum Computing: Lecture Notes. Preprint at https://arxiv.org/abs/1907.09415
Andrew Childs. Lecture Notes on Quantum Computing. Preprint at https://www.cs.umd.edu/~amchilds/qa/

Evaluation
Report on a topic of quantum computing agreed between the student and the professor.

Jury
Duarte Magano, Ariel Guerreiro, Maria de Fátima Mota.

Module

Optical fiber-based components and devices

Type

Tutorial

Contact hours

18

Professor/Researcher in charge

Marta Sofia dos Anjos Ferreira

Summary of Contents

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

- Optical fiber components: couplers / splitters, optical circulators, isolators, collimators, wavelength division multiplexers and types of fiber cables
- Fiber polarization management: polarization controllers, Faraday rotator mirrors, fiber polarizers, polarization scramblers
- Optical fiber multimode sensors: from design to applications. Here, the different components will be evaluated in a few practical examples.

Evaluation

Written report.

Bibliography

- Del Vilar, I., Matias, I. R., 2021. Optical fibre sensors: fundamentals for development of optimized devices, 1st Edition, IEEE Press Wiley, New Jersey.
- Mitschke, F., 2016. Fiber Optics Physics and Technology, 2nd Edition, Springer – Verlag, Germany.
- Fang, Z., Chin, K.K., Qu, R., Cai, H., 2012. Fundamentals of optical fiber sensors, 1st Edition, Wiley, New Jersey.

Jury

Marta Sofia dos Anjos Ferreira, Manuel Marques

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

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 (UP), Vítor Pereira (UP)

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.

References

Evaluation

Hand-in exercises

Jury

António Morais, António Onofre, Nuno Castro

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, decay widths, branching fractions.

4. Beyond the Standard Model: topics such as neutrino masses or vector-like leptons to be addressed in lectures and further discussed in hand-in exercises.

References

Evaluation

Hand-in exercises

Jury

António Morais, António Onofre, Nuno Castro