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Modules of Advanced Topics in Physics (TAF), 2026 – 27

Modules	Teachers
Conformal Field Theory (CFT)	António Antunes, Porto
Introduction to Topological Matter (ITM)	Eduardo Castro, Vitor Pereira, Bruno Amorim, Porto
Quantum Computing (QC)	Duarte Magano, Porto
Nano Magnetism (NM)	Gleb Kakazei, Porto
Group Theory and Applications to Condensed Matter Physics (GTACMP)	Agostinho Moreira, Porto
Large Infrastructures Characterization Techniques for Condensed Matter Physics (LICTCMP)	Rui Vilarinho, Porto
Micro-fabrication (MF)	Andre Pereira, Porto
Laser, Optics and Photonics (LOP)	Mário Ferreira, Aveiro
Computational Physics (CF)	António Luís Ferreira, José Pedro Coutinho, Aveiro
Climate variability and change (CVC)	Alfredo Rocha, Aveiro
Numerical simulation of the atmosphere and ocean (NSAO)	José Fortes, Aveiro
Estuarine Dynamics (ED)	Carina Lopes, João Dias, Aveiro
The Weather Research and Forecasting Model (WRF)	David Carvalho, Aveiro
Black holes and exotic compact objects in GR and beyond (BH)	Carlos Herdeiro, Eugen Radu, Hector Olivares, Aveiro
Plasmonics in 2D Materials and Nanoparticles (P2D)	Yuliy Bludov, Minho
Data Analysis in Particle Physics (DAPP)	Nuno Barros, Minho
Advanced Materials Preparation and Characterization (AMPC)	Bernardo Almeida, Minho



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Module: Conformal Field Theory (CFT)

Type: Lecture Series

Contact hours: 18

Professor/Researcher in charge: António Antunes, École normale supérieure - Paris

Summary of Contents

- Conformal field theories as fixed points of Renormalization group flow
- Kinematics and dynamics of two dimensional CFTs
- Non-invertible symmetries in two-dimensional CFTs
- Applications to the Ising model in the continuum and on the lattice

Evaluation

Oral presentation and discussion of a modern research paper



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Module: Introduction to Topological Matter (ITM)

Type: Lecture course

Contact hours: 18

Professor/Researcher in charge: Eduardo Castro, Vítor Pereira, Bruno Amorim, 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).

Evaluation

Written Report with oral presentation or Written Report



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Module: Quantum computing (QC)

Type: Lecture course

Contact hours: 18

Professor/Researcher in charge: Duarte Magano, U. Porto

Summary of Contents

- Basic principles of quantum computing: classical and quantum bits; quantum logic gates; the quantum circuit model; the Solovay-Kitaev theorem; Deutsch-Josza algorithm, Bernstein-Vazirani algorithm, Simon's algorithm.
- [optional] Advanced topics in quantum algorithms, with a focus on quantum singular value transformations and applications
- [optional] Quantum walks, with a focus on search tasks
- [optional] Quantum complexity theory, with a focus on query lower bounds methods

Evaluation

Oral examination covering one selected research article.



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Curricular Unit

Advanced Physics Topics

Module

Nanomagnetism

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

Glib Kakazei

Summary of Contents

Foundations of magnetism at the nanoscale. Fabrication and characterization. Magnetic nanoparticles and superparamagnetism. Interfaces, multilayers, and exchange bias. Spintronics and spin-orbit torques. Magnetization dynamics and magnonics. Topological magnetic textures. Applications, current challenges, and outlook

Evaluation

Oral presentation (30 minutes)



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Module: Group Theory and Applications to Condensed Matter Physics (GTACMP)

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 Co-representations. Properties of the magnetic point groups.

Evaluation

Written exam



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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 (μ SR) 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 μ SR) at large infrastructures using the respective beamline software.

Evaluation

Written Report or Written Report with oral presentation.



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Module

Micro and Nano-fabrication Techniques

Type

Lecture course

Contact hours

18

Professor/Researcher in charge

André Miguel Trindade Pereira

Summary of Contents

The micro- and nanofabrication activities will cover different techniques for patterning, printing, and thin-film deposition. Screen printing will include screen preparation and printing processes for the fabrication of patterned structures. Shadow masks will be used for pattern definition during material deposition. Sputtering deposition will be performed for the fabrication of thin films and multilayer structures, involving different materials and layer thicknesses. In addition, maskless photolithography will be used for the direct and flexible patterning of microstructures without the need for physical photomasks.

Overall, these activities will provide practical experience with complementary micro- and nanofabrication approaches, ranging from screen printing and shadow-mask patterning to thin-film deposition, multilayer fabrication, and maskless photolithography.

Evaluation

Oral Presentation



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Module: Lasers, optics and photonics (LOP)

Type: Lecture course

Contact hours: 18

Professor/Researcher in charge: Mario Ferreira, U. Aveiro

Summary of Contents

Light as Rays, Waves, and Photons

Lasers and Laser Light

Semiconductor Lasers and Amplifiers

Lasers Beams

Fiber Optics and Optical Communications

Nonlinear Optics

Optical Solitons

Evaluation

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



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Module: Computational Physics (CP)

Type: Lecture course

Contact hours: 18

Professor/Researcher in charge: António Luís Ferreira, 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"

Evaluation

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



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Module: Climate variability and change (CVC)

Type: Tutorial: Reading and Study assignment

Contact hours: 18

Professor/Researcher in charge: Alfredo Rocha, U. Aveiro

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.

Evaluation

Elaboration of a monograph and its oral presentation



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

Type: Tutorial: Reading and Study assignment

Contact hours: 18

Professor/Researcher in charge: José Fortes, U. Aveiro

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

Evaluation

Elaboration of a monograph and its oral presentation



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Module: Estuarine Dynamics (ED)

Type: Tutorial: Reading and Study assignment

Contact hours: 18

Professor/Researcher in charge: Carina Lopes, U. Aveiro

Summary of Contents

1. Estuarine morphology and hydrodynamics
2. Tides, tidal asymmetry, and river discharge interaction
3. Salt intrusion and estuarine circulation mechanisms
4. Estuarine mixing, transport processes, and residence time
5. Sediment transport and morphodynamics in estuaries
6. Human impacts, climate change, and sea level rise in estuaries

Evaluation

Elaboration of a monograph and its oral presentation



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Module: The Weather Research and Forecasting Model (WRF)

Type: Tutorial: Reading and Study assignment

Contact hours: 18

Professor/Researcher in charge: David Carvalho, U. Aveiro

Summary of Contents

Introduction to the WRF model

Physics parametrizations, initial and boundary data.

Regional climate simulations with WRF

Weather forecasts with the WRF model

Model and results evaluation.

Evaluation

Elaboration of a monograph and its oral presentation



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Module: Black Holes and Exotic Compact Objects in GR and beyond (BH)

Type: Lecture course

Contact hours: 18

Professor/Researcher in charge: Carlos Herdeiro, U. Aveiro

Lecturers: Carlos Herdeiro, Eugen Radu, Hector Olivares

Summary of Contents

Part 1

Black holes: astrophysical evidence and a theory (brief) timeline

Spherical black holes: Schwarzschild and Reissner-Nordström

Beyond spherical: Weyl class, Kerr and Kerr-Newman BHs

Aspects of scalar fields in gravity

Part 2

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 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

Evaluation

Problem sets and paper presentation.



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Module: Plasmonics in 2D Materials and Nanoparticles (P2D)

Type: Tutorial: Reading and Study assignment

Contact hours: 18

Professor/Researcher in charge: Yuliy Bludov, U. Minho

Summary of Contents

This module introduces students to the basic concepts of polaritonics, a field concerned with hybrid excitations resulting from the coupling of electromagnetic waves with mechanical excitations or charged particles in solid-state structures. The module focuses mainly on polaritons in two-dimensional (2D) materials, such as graphene, transition metal dichalcogenides, and black phosphorus, as well as on plasmonic phenomena in metal nanoparticles.

Detailed Programme

1. General overview of polaritons in noble metals, both in bulk materials and in the form of nanoparticles.
2. Electronic properties of graphene and its optical conductivity.
3. Surface plasmon–polaritons in graphene.
4. Methods for exciting surface plasmon–polaritons in graphene.
5. Polaritons in other 2D materials.

Evaluation

Students will be evaluated based on a written report on a selected topic related to the course.



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Module: Data Analysis in Particle Physics (DAPP)

Type: Tutorial: Reading and Study assignment

Contact hours: 18

Professor/Researcher in charge: Nuno Barros, U. Minho

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

To be defined



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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

Exam