UNIVERSITÀ DEGLI STUDI DI PADOVA

CORSI DI DOTTORATO

Course unit English denomination	Introduction to Topological Phases of Matter
Teacher in charge (if defined)	Di Liberto Marco Fedele
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	02/2024 – 06/2024
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	X Yes (50% minimum of presence) ☐ No
Course unit contents	In modern physics, topology has become a ubiquitous and fundamental concept, whose applications range from high-energy physics to condensed matter physics, and even classical physics. For example, Dirac or Weyl field theories are behind the description of graphene, Weyl semimetals and the topological features of their bands, Chern-Simons field theories are behind the integer and fractional quantum Hall effect in 2D electron gases. Topology characterizes quantum phases in which a new type of order, based on global properties rather than local ones, emerges. This course aims at giving an overview of the main achievements in this field and connecting it to the current ongoing research, including the role of entanglement, quantum simulation and quantum computation. INTRODUCTION - Motivation and generalities - Berry phase, spin in a magnetic field, Dirac monopole and gauge freedom, Bloch bands TOPOLOGICAL BAND THEORY - A case study: The Su-Schrieffer-Heeger model. Polarization, Wannier centers, Wilson loop, winding number and edge modes - Chern insulators: Berry curvature, Chern number, Integer quantum Hall effect (QHE), TKNN formula. Examples: Haldane and Qi-Wu-Zhang models. - Time-reversal invariant topological insulators: quantum spin-Hall effect (QSHE) and its Z_2 invariant. Example: the Bernevig-Hughes-Zhang (BHZ) model - Topological insulators in higher dimensions, the Altland-Zirnbauer classification, crystalline topological insulators FRACTIONAL QUANTUM HALL EFFECT AND TOPOLOGICAL ORDER

	- Electrons in a magnetic field in 2D, Landau levels - Conductivity and Hall response - The lattice limit and the Hofstadter model - Interactions, fractional Quantum Hall effect, Laughlin wavefunction - Hole excitations, abelian anyons, composite particles - Topological order, Kitaev's toric code, perspectives for quantum computing
Learning goals	Students will acquire the main concepts regarding topological systems, their characterization and properties that are relevant to appreciate the scientific developments in the last years. They will be able to identify phases and states of matter with different topological features, define and calculate topological invariants starting from the band structure or from the ground state interacting wavefunction. With these abilities and knowledge, the student will have the tools to approach the most recent scientific literature in condensed matter physics, including topological materials, or more in general, those employing topological field theories and appreciate the impact of topology in contemporary physics.
Teaching methods	Frontal lessons
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	Quantum Mechanics, elements of electromagnetism and band theory, elements of many-body theory
Examination methods (in applicable)	Oral exam
Suggested readings	- János K. Asbóth, László Oroszlány, András Pályi, A Short Course on Topological Insulators: Band-structure topology and edge states in one and two dimensions, Lecture Notes in Physics, 919 (2016) - A. Bernevig, Topological Insulators and Topological Superconductors, Princeton University Press (2013) - E. Fradkin, Field Theories of Condensed Matter, Cambridge University Press (2013) - D. Tong, Lectures on the Quantum Hall Effect (2016)
Additional information	None