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| Course Title | **LATTICE GAUGE THEORIES** | | | | |
| Course Code | **PHY 655** | | | | |
| Course Type | Elective | | | | |
| Level | Graduate | | | | |
| Year / Semester | $2^{nd}$ year / $3^{rd}$ or $4^{th}$ semester of graduate studies | | | | |
| Teacher’s Name | Constantia Alexandrou, Haralambos Panagopoulos | | | | |
| ECTS | 10 | Lectures / week | 2 (2 hours each) | Laboratories / week | |
| Course Purpose and Objectives | Investigate the Physics of Quantum Fields via non-perturbative methods on a spacetime lattice.<br>Study in depth both the theoretical and computational aspects of Lattice Gauge Fields.<br>Explore the phase structure and transitions of strongly coupled physical systems. | | | | |
| Learning Outcomes | By the end of the course students are expected to:<br>• Formulate the quantum description on a spacetime lattice for physical systems containing coupled scalar, fermion and gauge fields.<br>• Carry out computations in lattice field theories via expansions in the hopping parameter, in strong coupling and in weak coupling.<br>• Investigate the quantum continuum limit of lattice field theories, addressing issues such as confinement, asymptotic freedom and bulk transitions.<br>• Assess alternative lattice formulations with respect to locality, chiral symmetry, rate of approach to the continuum limit, phase structure.<br>• Construct state-of-the-art simulation algorithms for all types of quantum fields.<br>• Determine physical observables of quantum field theories, such as their spectrum and phase transitions, via numerical simulations. | | | | |
| Prerequisites | None | | Required | PHY 650 | |
| Course Content | The path integral approach to quantization. Euclidean quantum field theory. Quantum fields on a lattice Continuum limit and critical behaviour.<br>The free scalar field on the lattice.<br>Fermions on the lattice. Wilson fermions, Kogut-Susskind staggered fermions, Nielsen-Ninomiya theorem. | | | | |

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| | Abelian gauge fields on the lattice and compact QED.<br>Non-Abelian gauge fields on the lattice, compact QCD.<br>Strong coupling expansion. Hopping parameter expansion.<br>Quark-antiquark potential. Glueball spectrum. Phase structure of lattice gauge theory.<br>Weak coupling expansion in scalar theories and in QCD.<br>The continuum limit of lattice QCD. The beta function and asymptotic freedom.<br>Monte Carlo Methods. Numerical simulation and Markov processes. Algorithms: Metropolis, Heat bath, Overrelazation. Simulation of fermions: Hybrid Monte Carlo, Multiboson algorithms.<br>Deconfinement and chiral phase transitions. High temperature phase of QCD. |
| Teaching Methodology | The 4 hours of weekly lectures typically consist of: Brief review of previous lectures, introduction to new concepts, discussion and questions by the instructor and the students, exercises and applications of increasing difficulty, summary and conclusions, identification of points for reflection and discussion during the following lecture. Emphasis is placed on modern extensions and applications of the course material.<br>Lectures are delivered mostly on the blackboard, allowing for better comprehension, while descriptive elements or graphics are projected on a screen via a PC. Certain complex problems, whole quantitative investigation necessitates a numerical approach, are addressed interactively via the computer software Mathematica and via prototype simulation algorithms. All material shown on the screen is also uploaded on the course's web page.<br>Some of the topics are presented in class by the students themselves. Each student is expected to make two presentations during the semester. |
| Bibliography | Suggested books:<br>H. J. Rothe, Lattice Gauge Theories - An Introduction (World Scientific, 2012).<br>I. Montvay - G. Münster, Quantum Fields on a Lattice (Cambridge University Press, 1997).<br>C. Gattringer - C. B. Lang, Quantum Chromodynamics on the Lattice (Springer, 2010).<br>F. Knechtli - M. Günther - M. Peardon, Lattice Quantum Chromodynamics: Practical Essentials (Springer, 2017).<br>M. Creutz, Quarks, Gluons and Lattices (Cambridge University Press, 1985).<br>T. Degrand - C. DeTar, Lattice Methods for Quantum Chromodynamics (World Scientific, 2006).<br>For special topics / further study, readings will be drawn from recent articles. |

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| Assessment | • Class presentations 40%<br>• Final exam 60% |
| Language | Greek/English (depending on the audience). The bibliography is in English. |