



COURSE UNIT (MODULE) DESCRIPTION

Course unit (module) title	Code
Quantum field theory II	

Lecturer(s)	Department(s) where the course unit (module) is delivered
Coordinator: Vytautas Dūdėnas	Teorinės fizikos ir astronomijos institutas
Other(s): Simonas Draukšas	

Study cycle	Type of the course unit (module)
Master studies	selectable lecture

Mode of delivery	Period when the course unit (module) is delivered	Language(s) of instruction
Lecture	Spring semester: February till June	English

Requirements for students	
Prerequisites: Quantum Mechanics, Special Relativity, Quantum field theory I	Additional requirements (if any):

Course (module) volume in credits	Total student's workload	Contact hours	Self-study hours
5	140	64	76

Purpose of the course unit (module): programme competences to be developed
The aim of the course is to give the student a solid background in quantum field theory, that is needed to understand the current research in particle physics. After taking this course, the student is expected to be able to calculate first order corrections to QFT amplitudes. He is also expected to understand the construction of abelian and non-abelian gauge theories, spontaneous symmetry breaking and the renormalization group.

Learning outcomes of the course unit (module)	Teaching and learning methods	Assessment methods
Scalar QED theory	Lecture and reading (self study)	exam
Renormalization in scalar QED	Lecture and reading (self study)	exam
Fermions, Path integrals for fermions and QED	Lecture and reading (self study)	exam
Renormalization in QED	Lecture and reading (self study)	exam
Non-abelian gauge theory, QCD, BRST symmetry	Lecture and reading (self study)	exam
Wilson renormalization group and critical exponents	Lecture and reading (self study)	exam
Spontaneous symmetry breaking and the Standard model	Lecture and reading (self study)	exam

Content: breakdown of the topics	Contact hours							Self-study work: time and assignments	
	Lectures	Tutorials	Seminars	Exercises	Laboratory work	Internship/work placement	Contact hours	Self-study hours	Assignments
1. Overview of the course and some reminder Noether, S-matrix, Greens functions – reminder, Feynman rules, overview of the course.	2						2	2	Reading

2. Path integral Gaussian integral, Path integral in QM and then in QFT. Classical limit $\hbar \rightarrow 0$. Generating functionals, free propagator, 4pt function – equivalence to canonical formulation in terms of Feynman rules.	4						2	2	Reading
3. Scalar QED Klein Gordon, Global-local U(1), photon Kinetic term, Scalar QED Lagrangian, gauge choice, Free photon field	2		1				3	4	Reading, homework
4. Scalar QED, photon propagator Ward identity and gauge symmetry, Klein-Gordon propagator, photon propagator, Fadeev-Popov gauge fixing	2		1				3	4	Reading, homework
5. Scalar QED, Feynman rules LSZ Reduction, Derive Feynman rules from path integral example, Feynman rules for SQED, Cross-sections and decay rates, examples: Moller scattering, $ee \rightarrow \gamma\gamma$ and Ward identity, photon polarization sum	2		2				6	6	Reading, homework
6. Radiative corrections Intro to renormalization, example: quartic scalar interaction, renormalized SQED Lagrangian, Divergent integrals and regularization, Photon propagator	4		2				6	6	Reading, homework
7. Example of renormalization renormalization in the modified minimal subtraction scheme, getting divergences to fix all counterterms in SQED, Ward identity	2		2				4	6	Reading, homework
8. Fermions reminder about gamma matrices, spinors, Dirac equation, trace identities. Path integral with fermions. Yukawa theory, Fermion Loops, summary of Feynman rules.	2		2				4	6	Reading, homework
9. QED and renormalization Discrete symmetries of QED, renormalized Lagrangian, 1-loop corrections to Photon, Fermion propagators and vertex function. QED β function.	4		2				6	6	Reading, homework
10. Non-Abelian Gauge theory non-abelian Groups, gauge symmetry, representations, first look on QCD, FP gauge fixing.	2		2				4	6	Reading, homework
11. QCD Feynman rules, QED interactions, example $qg \rightarrow qg$, radiative corrections, divergences and QCD beta function.	4		1				5	6	Reading, homework
12. BRST Abelian, non-abelian, BRST operator, physical states	2		1				3	6	Reading, homework
13. Wilson RG and critical exponents	4		1				5	6	Reading, homework
14. Spontaneous Symmetry breaking (SSB) Global symmetries, Goldstone theorem, SU(N)	2		1				3	4	Reading, homework
15. SSB 181-191 Gauge symmetry breaking – Abelian, massive gauge bosons, Unitary gauge fixing, general renormalizable gauge fixing, Non-abelian gauge symmetry breaking	2		1				3	4	Reading, homework
16. Standard Model Electroweak symmetry breaking, Higgs potential Gauge boson interaction, Weak interactions, Fermion masses, Higgs interactions.	4		1				5	2	Reading, homework
Total	44		20				64	76	

Assessment strategy	Weight, %	Deadline	Assessment criteria
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Homeworks	33	As announced in the syllabus:	Turning in on time and the correctness of the solutions.
Exam	67		Passing the written and the oral part

Author	Year of publication	Title	Issue of a periodical or volume of a publication	Publishing place and house or web link
Compulsary reading				
1. Lucian Harland-Lang		Advanced Quantum Field Theory (lecture notes)		https://www2.physics.ox.ac.uk/sites/default/files/profiles/harland-lang/aqft-48484.pdf
2. Matthew D. Schwartz	2014	Quantum Field Theory and the Standard Model	Pages 151-269	Cambridge University Press; ISBN 9781107034730
3. Michael E. Peskin and Daniel V. Schroeder	1995	An Introduction to Quantum Field Theory;	Pages 265-275; 393-451	Reading, USA: Addison-Wesley; ISBN 0-201-50397-2
Optional reading				
4. Matthew D. Schwartz	2014	Quantum Field Theory and the Standard Model		Cambridge University Press; ISBN 9781107034730
5. Michael E. Peskin and Daniel V. Schroeder	1995	An Introduction to Quantum Field Theory;		Reading, USA: Addison-Wesley; ISBN 0-201-50397-2
6. P. B. Pal	2010	Dirac, Majorana and Weyl fermions		arXiv:1006.1718 [hep-ph]
7. I. J. R. Aitchison and A. J. G. Hey	2013	Gauge theories in particle physics: A practical introduction. Vol. 1: From relativistic quantum mechanics to QED		Bristol, UK: IOP (2003) 406p
8. I. J. R. Aitchison and A. J. G. Hey	2014	Gauge theories in particle physics: A practical introduction. Vol. 2: Non-Abelian gauge theories: QCD and the electroweak theory		Bristol, UK: IOP (2004) 454 p
9. A. Zee	2003	Quantum Field Theory in a Nutshell		Princeton University Press; ISBN 0-691-01019-6 (2003).
10. F. Olness and R. Scalise	2011	Regularization, Renormalization, and Dimensional Analysis: Dimensional Regularization meets Freshman E & M	Am. J. Phys. 79 (2011) 306	[arXiv:0812.3578 [hep-ph]]
12. Warren Siegel	2017	Fields		http://arxiv.org/abs/hep-th/9912205 or http://insti.physics.sunysb.edu/~siegel/Fields4.pdf
13. Stefan Pokorsky	2000	Gauge Field Theories		Cambridge University Press; ISBN 0-521-47816-2 (2000)
14. F. Jegerlehner	1991	Renormalizing The Standard Model		PSI-PR-91-08, Apr 1991
15. S. Weinberg	1995	The Quantum Theory of Fields, I and II,		Cambridge University Press; ISBN 0-521-58555-4
16. J. C. Romao and J. P. Silva	2012	A resource for signs and Feynman diagrams of the Standard Model		arXiv:1209.6213 [hep-ph]
17. John C. Collins	1984	Renormalization		Cambridge University Press
18. M. Bohm, A. Denner, H. Joos	2001	Gauge theories of strong and electroweak interactions		B.G.Teubner Stuttgart Leipzig/Wiesbaden ISBN-13: 978-3-322-80162-3
19. Matthew Robinson	2011	Symmetry and the Standard model		Springer-Verlag New York, ISBN 978-1-4419-8267-4
20. David Tong	2007	Quantum Field Theory, University of Cambridge Part III Mathematical Tripos		http://www.damtp.cam.ac.uk/user/tong/qft/qft.pdf