

UR an international PhD student

**COURSE SYLLABUS – DOCTORAL SCHOOL
EDUCATION CYCLE FROM 2024/2025 TO 2027/2028
AND
EDUCATION CYCLE FROM 2025/2026 TO 2028/2029**

GENERAL INFORMATION ABOUT THE SUBJECT	
Subject title	OPTIONAL SPECIALISED SUBJECT Introduction to Quantum Field Theory
Name of the unit offering the subject	Doctoral School at the University of Rzeszów
Type of subject (<i>compulsory, optional</i>)	Specialist elective course
Year/semester	Year II / semester III and year III / semester V
Discipline	<i>physics</i>
Language	English
Name and surname of the course coordinator	Prof. Roman Pasechnik
Name and surname of the person(s) teaching the subject	Prof. Roman Pasechnik
Prerequisites	Quantum mechanics at undergraduate level, including states and operators, the harmonic oscillator and elementary perturbation theory; basic special relativity and classical mechanics; linear algebra, Fourier transforms and differential equations. Relativistic notation and the oscillator algebra are briefly reviewed. No previous QFT course is required. English at CEFR B2 level, including scientific terminology.
COURSE SUMMARY	
(synthetic description of the content and objectives of the course; 100-200 words)	
The course introduces the quantum-field description of relativistic particles and their interactions. Its central question is how local relativistic quantum fields produce observable scattering probabilities. The canonical approach connects Lorentz covariance, the action principle and Noether's theorem to the Klein–Gordon field, oscillator quantization, Fock states and causal commutators. Propagators, the interaction picture, Dyson expansion and Wick contractions then lead to a complete lowest-order scalar scattering calculation, including flux, phase space and identical-particle counting. Selected Dirac-field and gauge-principle material introduces the structure of QED. Higher-order diagrams motivate the limitations of perturbative predictions. Blackboard calculations and guided discussion develop explicit conventions, physical interpretation and consistency checks. Assessment consists of an individual written report solving five analytic problems. The course supports further study of particle physics, radiation and effective descriptions of matter.	

LEARNING OUTCOMES FOR THE COURSE AND VERIFICATION METHODS				
Learning outcome symbol	Expected learning outcomes	Reference to learning outcomes for level 8 PRK qualifications (symbol)	Form of teaching (lectures, practical classes, etc.)	Assessment methods (e.g. test, oral examination, written examination, project, etc.)
Knowledge	Knowledge: <i>knows and understands, has knowledge</i>			
P8S_WG1	Knows and understands selected foundations of relativistic QFT: Lorentz covariance, action and symmetry, canonical quantization, particle states, causal commutators, propagators and perturbative scattering. Recognizes the basic field content and interaction structure of QED.	P8S_WG	Seminar: blackboard derivations and discussion	Report problems 1–5: derivations and physical interpretation.
P8S_WG2	Understands the role of QFT in contemporary physics and why higher-order and nonperturbative methods are needed beyond simple leading-order predictions. Distinguishes established calculations in the course from questions requiring further research.	P8S_WG	Seminar: blackboard derivations and discussion	Report problem 5: limitations and further-study discussion.
P8S_WG3	Knows and uses the conceptual vocabulary of QFT, including fields, states, propagators, amplitudes, diagrams, symmetries and observables, and explains these concepts accurately in scientific English.	P8S_WG	Seminar: blackboard derivations and discussion	Terminology and explanations throughout the written report.
P8S_WK1	Understands connections between quantum fields, radiation and matter, and can discuss how this theoretical knowledge informs spectroscopy, particle experiments or quantum-material research, with a balanced account of technological significance and limits.	P8S_WK	Seminar: blackboard derivations and discussion	Report conclusion: one scientific application and its wider significance.
Skills	Skills: <i>able to</i>			
P8S_UW1	Formulates a defined scalar-field problem using an action and explicit conventions. Derives its field equation, a conserved quantity and the basic quantized free-field construction; selects appropriate consistency checks and draws physical conclusions.	P8S_UW	Seminar: blackboard derivations and discussion	Report problems 1–2: analytic formulation and checks.
P8S_UW2	Uses lecture notes and scientific literature to reconstruct a propagator, a lowest-order scattering amplitude and a corresponding observable; applies the method to a modest variation of a taught example.	P8S_UW	Seminar: blackboard derivations and discussion	Report problems 3–5: independent reconstruction and a limiting-case variation.

LEARNING OUTCOMES FOR THE COURSE AND VERIFICATION METHODS				
Learning outcome symbol	Expected learning outcomes	Reference to learning outcomes for level 8 PRK qualifications (symbol)	Form of teaching (lectures, practical classes, etc.)	Assessment methods (e.g. test, oral examination, written examination, project, etc.)
P8S_UW ₃	Critically evaluates a calculation by checking dimensions, normalization, causal interpretation, combinatorial factors and kinematic limits. States the assumptions under which the result applies and distinguishes a model prediction from an experimental claim.	P8S_UW	Seminar: blackboard derivations and discussion	Validity checks and discussion in report problems 3–5.
P8S_UK ₆	Uses English-language scientific sources and presents a structured written explanation of a QFT calculation in English, with clearly defined notation, traceable reasoning and appropriate references.	P8S_UK	Seminar: blackboard derivations and discussion	Organization, explanations and citations in the report.
Social competences	Social competences: <i>is ready to</i>			
P8S_KK ₃	Recognizes the value of theoretical knowledge in resolving conceptual and practical physics problems, and the need for further knowledge or methods when a calculation exceeds the assumptions of the elementary framework.	P8S_KK	Seminar: blackboard derivations and discussion	Report conclusion: justified scope and limits of the methods used.

FORMS OF TEACHING ACTIVITIES, NUMBER OF HOURS AND CREDITS						
Semester (no.)	Lecture	Practical/Seminar	Lab	Practical	Other	Number of ECTS points
III and V	-	15 academic hours	-	-	-	2

TEACHING METHODS

Interactive blackboard teaching with complete derivations for the scalar-field core; guided interpretation of diagrams; short checks of assumptions, signs, dimensions and limiting cases; scientific discussion; independent study of lecture notes; analytic problem solving presented in a written report. The Dirac/QED extension introduces the field content, particle interpretation and gauge structure. No programming is required.

PROGRAMME CONTENT

Delivery: 12, 13 and 14 October 2026, 09:00–13:00 each day, with a 15-minute break. The allocations below include discussion and recap; total teaching time is 15 academic hours.

12 October — Fields, symmetries and particles (5 academic hours). Relativistic motivation, notation and scalar-field transformations (0.5 h); action, Euler–Lagrange equation, Noether’s theorem and the translation current (1 h); Klein–Gordon Hamiltonian, oscillator-to-field canonical quantization, mode expansion, normal ordering, Fock states and invariant normalization (3 h); guided checks and recap (0.5 h).

13 October — Causality and perturbative interactions (5 academic hours). Wightman function, local commutator, spacelike separation, time ordering and the scalar Feynman Green function (1.5 h); interaction picture, Dyson expansion and Wick contractions (2 h); first-order two-to-two scalar scattering and the vertex combinatorics (1 h); checks and discussion (0.5 h).

14 October — From amplitudes to observables (5 academic hours). Complete the scalar scattering prediction: invariant amplitude, incident flux, two-body phase space, Mandelstam invariants and identical-final-state counting (2 h). Selected introduction to the Dirac equation, particles and antiparticles, fermionic statistics, local U(1) symmetry and the QED interaction (1.5 h). Structure of higher-order scalar diagrams and the need to control perturbative approximations (0.5 h). Synthesis, connections to the students’ research areas, report guidance and discussion (1 h).

The principal worked example is lowest-order two-to-two scattering in real scalar quartic theory. The Dirac equation and QED are introduced at a conceptual and structural level. Advanced spinor representation theory, full fermion/photon quantization, loop-integral evaluation and QED scattering calculations are outside the assessed scope.

COURSE COMPLETION REQUIREMENTS (ASSESSMENT CRITERIA)

Assessment: graded individual written take-home examination, submitted as one analytic problem-solving report. No oral examination or presentation is required. The report is the sole summative assessment and contains solutions to the following five substantial problems based on material taught in the course.

1. Action, symmetry and conserved energy (20 marks). Derive the Klein–Gordon equation, conjugate momentum, translation current and Hamiltonian from the real scalar action; verify conservation and interpret the energy.
2. Quantized fields and particle states (20 marks). With a declared mode normalization, derive the ladder-operator algebra, check the equal-time field commutator and obtain the free Hamiltonian. Explain normal ordering and verify the energy and normalization of a one-particle state.
3. Correlation and causality (20 marks). Construct the free scalar two-point function and commutator; establish vanishing of the commutator at spacelike separation. Construct the time-ordered propagator and check its Green-function equation, stating the convention-dependent factors of i . Explain why a nonzero spacelike correlator does not imply superluminal signalling.
4. From the interaction to the amplitude (20 marks). Obtain the Dyson expansion through second order. Use its first-order term and explicit Wick contractions to derive two-to-two scattering in real scalar quartic theory, showing the factorial cancellation and momentum-conservation factor.
5. From the amplitude to a prediction (20 marks). Derive the centre-of-mass two-body cross section using flux and phase space, applying one consistent convention for identical final particles. Check dimensions and the high-energy behaviour. Briefly identify the fields and interaction in the QED Lagrangian introduced in class and explain the role of local $U(1)$ symmetry. Conclude with approximation limits and one connection to a scientific application and its wider significance.

Detailed problem statements are provided in the student assignment. Solutions must explain intermediate steps, define notation and assumptions, and identify sources.

Marking: each problem carries 12 marks for analytic reasoning and correctness, 5 for physical interpretation and 3 for checks, conventions and clarity. Total: 100 marks. All five problems must be substantively attempted. A pass requires at least 50 marks overall and at least 8/20 on each problem, demonstrating minimum coverage of the core topics.

Grade bands, subject to those pass conditions: 90–100 = 5.0; 80–89 = 4.5; 70–79 = 4.0; 60–69 = 3.5; 50–59 = 3.0; failure to meet the pass conditions = 2.0. Attendance and participation support learning but are not substitutes for demonstrated achievement in the report.

The lecturer will announce the submission deadline, revision arrangements and applicable attendance requirements before assessment begins.

TOTAL WORKLOAD REQUIRED FOR A DOCTORAL STUDENT TO ACHIEVE THE SET OBJECTIVES IN TERMS OF HOURS AND ECTS POINTS	
Form of activity	Average number of hours to complete the activity
Hours spent in direct contact resulting from the study programme	15
Other participation with the teacher (consultation and feedback)	1
Independent study, reconstruction of derivations and preparation of the written problem-solving report	44
TOTAL HOURS	60
TOTAL NUMBER OF ECTS POINTS *	2
LITERATURE	
Basic literature:	Main textbook: Michael E. Peskin and Daniel V. Schroeder, An Introduction to Quantum Field Theory. Addison-Wesley, 1995.
Supplementary literature:	David Tong, Lectures on Quantum Field Theory, selected sections on classical fields, canonical quantization and interacting fields. University of Cambridge. https://www.damtp.cam.ac.uk/user/tong/qft.htm

**(1 ECTS POINT CORRESPONDS TO 25–30 HOURS OF TOTAL WORK REQUIRED OF A DOCTORAL STUDENT TO ACHIEVE THE INTENDED LEARNING OUTCOMES)*

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Date and signature of the course lecturer

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Approval of the Head of the Unit or authorised person