TEACHING INSTRUCTIONAL DESIGN (BRP)

COURSE

QUANTUM FIELD THEORY

by

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PREFACE

This Teaching Instructional Design (BRP) contains the lesson plan for one semester, designed to be used as an instruction reference for the Quantum Field Theory course in the University of Indonesia Faculty of Mathematics and Natural Sciences Undergraduate Program in Physics. The Quantum Field Theory course is held during the 7^{th} term of the undergraduate program in physics for members of the Theoretical Nuclear and Particle Physics elective. This course requires students to have completed the Classical Mechanics course, Electromagnetic Field 1 course, Classical Field theory course, Quantum Mechanics 1 course, and Quantum Mechanics 2 course as a prerequisite.

In this course, students will learn the quantization of fundamental fields in nature. Students will also learn to formulate those fields in relativistic terms. The greatest portion of this course will be allocated to the discussion of scalar, gauge, and fermion fields. Besides their quantization, this course will also discuss symmetry (both spacetime and internal). Specifically, emphasis will be given on theories that are invariant to global nor local, Abelian, or non-Abelian.

This Teaching Instruction Design is compiled as a reference during the learning process, both for lecturers and for students so that the content of this course is delivered well, and the teaching goals of this course are achieved.

Depok, November 2017

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I. General Information

1.	Name of Program / Study Level	:	Physics / Undergraduate
2.	Course Name	:	Quantum Field Theory
3.	Course Code	:	SCFI604413
4.	Semester	:	7
5.	Credit	:	4 credits
6.	Teaching Method(s)	:	Interactive lecture
7.	Prerequisite course(s)	:	Classical Mechanics, Electromagnetic Field Theory, Classical Field Theory, Quantum Mechanics 1, Quantum Mechanics 2
8.	Requisite for course(s)	:	Undergraduate Thesis
9.	Integration Between Other Courses	:	-
10.	Lecturer(s)	:	Handhika Satrio Ramadhan, Ph.D.
11.	Course Description	:	Special Theory of Relativity; Lagrangian and Hamiltonian formulation for continuous systems; conservation theorem for continuous systems, and the energy-momentum tensor; Lagrangian of classic relativistic fields such as scalar and electromagnetic fields; Fermion field Lagrangian; Internal symmetry; Global transformation; Local transformation; Quantum Electrodynamics (QED); Non-abelian group transformation; Renormalization.

II. Course Learning Outcome (CLO) and Sub-CLOs

A. CLO

After the completion of this course, it is hoped that students are able to understand the quantization of fundamental fields through the second quantization formalism. Students are also able to connect the relationship between the symmetry of a Lagrangian with conserved quantities, specifically, between phase transformation invariance (both global and gauge) and the conservation of Noether's charge. It is also hoped that students understand the concept of invariance towards U(1) (Abelian) transformations which is the foundation of QED (quantum electrodynamics) theory, and non-Abelian transformations which is the foundation of the Standard Model. Lastly, it is hoped that students understand the Path Integral formalism as an alternative to quantizing fields, are introduced to the fundamentals of renormalization, and recognize the importance of Spontaneous Symmetry Breaking in the unification of fundamental interactions in nature.

B. Sub-CLO

It is hoped that after the completion of this course students are able to:

1. understand Lorentz transformation (C1),
2. formulate the concept of Maxwell's electrodynamics in covariant terms (C2),
3. recognize the concept of Lagrangian and the principle of least action for continuous systems (C1),
4. derive equations of motion from a Lagrangian for electromagnetic fields (Maxwell) and scalar fields (Klein-Gordon) (C3),
5. recognize Dirac (Fermion) fields (C1),
6. explain the relationship between symmetry and conserved quantities in the framework of Noether's theorem (C3),
7. understand the energy-momentum tensor (C3),
8. recognize the concept of gauge transformation (C1),
9. formulate scalar field Lagrangians that are invariant towards gauge transformations (Abelian and non-Abelian) (C2),
10. understand quantum electrodynamics theory (C1),
11. quantize canonical and fundamental fields (C3),
12. understand the Feynman Path Integral method and Feynman's rule as an alternative method in quantizing fields (C3),
13. understand perturbation theory and Wick's theorem (C3),
14. draw Feynman diagrams for simple processes (C2),
15. calculate the S-matrix and cross-section of several simple processes (reactions) (C3),

16. understand why renormalization has to be done and do normalizations on the calculations for simple reactions (C3),
17. understand the fundamentals of Quantum Chromodynamics and the Standard Model (C1),
18. draw the relation between the phenomena of phase transitions and spontaneous symmetry breaking (C2),
19. formulate the Higgs mechanism (C3).

III. Teaching Plan

Week	Sub-CLO	Study Materials	Teaching Method	Time Required	Learning Experiences (*O-E-F)	Sub-CLO Weight on Course (%)	Sub-CLO Achievement Indicator	References
1	1	Special Theory of Relativity: Lorentz transformation, 4-invariance, Lorentz group, tensor algebra, and calculus	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain the concept of the special theory of relativity qualitatively and technically using tensor calculus	1 and 2
2	2	Maxwell Electrodynamics: 4-potential, the Maxwell field tensor, covariant formulation for Maxwell's equations, gauge freedom	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain the covariant form of Maxwell's equations	1 and 2
3	3	Lagrangian Formulation: Lagrangian of continuous systems, the least action principle, Lagrangian of scalar fields, and the Klein-Gordon equation of motion	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain the use of Lagrangians in field theory	1 and 2
4	4	Maxwell field Lagrangian, symmetry and group theory, Noether's theorem, the energy-momentum tensor	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain the Maxwell field Lagrangian, symmetry, Noether's theorem, and the energy-momentum tensor	1 and 2
5	5	Gauge Invariance: global transformations, local transformation, gauge symmetry	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain the concept of local and global transformations, and gauge symmetry	1 and 2
6	6	Gauge Invariance:	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	10	Students can explain Abelian gauge theories,	1 and 2

		Abelian gauge theory, non-Abelian gauge theory, Yang-Mills theory.					non-Abelian gauge theories, and the Yang-Mills theory	
7	6	Canonical Quantization: conjugate momentum, particle number operator, commutation properties for real and complex Klein-Gordon fields, Dirac fields, and gauge fields	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	10	Students can formulate the second equation and the concept of quantum fields	1 and 2
8	**Midterm Exam**							
9	6	Path Integral: path integrals in quantum mechanics, perturbation theory, and the S matrix, generating functional, Feynman's rule	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	10	Students can formulate Feynman's path integral and its use in quantum mechanics	1 and 2
10	6	Interacting Fields: 2-point function, n-point function, Feynman diagrams	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	10	Students can explain the use of Feynman diagrams	1 and 2
11	7	Scattering cross-section, φ^4 scalar field theory, Quantum Electrodynamics	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	10	Students can calculate the cross-section of a scattering process, explain scalar field theory, and quantum electrodynamics	1 and 2
12	7	Renormalization: divergences in quantum field theory, dimensional regularization	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain divergences in quantum field theory and dimensional regularization.	1 and 2
13	7	Renormalization: loop expansion, Counter terms	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	4	Students can explain loop expansion and Counter terms	1 and 2

14	7	Spontaneous symmetry breaking, vacuum condition, phase transition	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	6	Students can explain the concept of spontaneous symmetry breaking	1 and 2
15	8	Spontaneous symmetry breaking, Goldstone's theorem, Higgs mechanism	Face-to-face lecturing	2 x 50 minutes	70% O, 15% E, 15% F	4	Students can explain symmetry breaking and the occurrence of the Higgs mechanism	1 and 2
16	**Final Exam**							

*) O : Orientation
E : Exercise
F : Feedback

References:

1) Lewis H. Ryder, *Quantum Field Theory*, Cambridge University Press.
2) Michael E. Peskin and Daniel V. Schroeder, *Introduction to Quantum Field Theory*, Addison-Wesley Publishing.

IV. Assignment Design

Week	Assignment Name	Sub-CLO	Assignment	Scope	Working Procedure	Deadline	Outcome
2	Individual Assignment 1	1, 2	Problem set	Special theory of relativity and Maxwell electrodynamics	Individual homework	1 week	Individual worksheet
4	Individual Assignment 2	3, 4, 5	Problem set	Lagrangian Formulation: Lagrangian and the least action principle for classical fields, equation of motion for scalar fields (Klein-Gordon), Noether's theorem, energy-momentum tensor, gauge field tensor	Individual homework	1 week	Individual worksheet
6	Individual Assignment 3	6, 7, 8, 9	Problem set	Gauge Transformation: global and local transformation, U(1) (Abelian) gauge theory, non-Abelian gauge transformation, SU(2) (Yang-Mills) gauge theory	Individual homework	1 week	Individual worksheet
10	Individual Assignment 4	10, 11, 12, 13, 14, 15	Problem set	Canonical Quantization and Field Interaction: scalar, vector, and spinor field quantization, path integral formulation, 2-point function, QED	Individual homework	3 weeks	Individual worksheet
13	Individual Assignment 5	16, 17	Reading material according to references	φ^4 scalar field theory renormalization, quantum electrodynamics theory renormalization	3–4-person group assignment	2 weeks	Individual worksheet
14	Individual Assignment 6	18, 19	Problem set	Spontaneous symmetry breaking: phase transitions and the Higgs mechanism	Individual Homework	1 week	Presentation file in PowerPoint

V. Assessment Criteria (Learning Outcome Evaluation)

Evaluation Type	Sub-CLO	Assessment Type	Frequency	Evaluation Weight (%)
Individual Assignment	1-4	Answer sheet	6	20
Group Assignment	5-6	Assessment sheet	2	20
Midterm Exam	1-3	Answer sheet	1	30
Final Exam	4-6	Answer sheet	1	30
Total				**100**

VI. Rubric

A. Criteria of Assignment and Exam Scores

Score	Answer Quality
100	Answer is very precise and all the concept and main component are explained completely
76-99	Answer is fairly precise and the concept and main component are explained fairly complete
51-75	Answer is less precise and the concept and main component are explained less complete
26-50	Answer is poorly precise and the concept and main component are explained poorly complete
<25	Answer is wrong