TEACHING INSTRUCTIONAL DESIGN (BRP)

COURSE

CLASSICAL FIELD THEORY

by

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PREFACE

This Teaching Instruction Design (BRP) contains lesson plans for one semester, designed to be used as an instruction reference for the Classical Field Theory course in the Universitas Indonesia Department of Physics. This course is held during the 5^{th} term of the undergraduate program in physics for members of the Theoretical Nuclear and Particle Physics specialization. This course requires students to have completed the Classical Mechanics and the Electromagnetic Field 1 course as a prerequisite.

In this course, students will learn the classical fundamental forces in nature. Students will also learn to formulate those forces in covariant (relativistic) terms. The greatest portion of this course will be allocated to discussing gravitational fields as the only classical field that has yet to be quantized. To delve into modern gravitational fields, students will be introduced to concepts in differential geometry, starting from the concept of manifold, culminating in the quantities in the Ricci curvature tensor. These mathematical tools are needed to understand the General Theory of Relativity, wherein said theory gravitational fields are interpreted as curvature in spacetime.

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, September 2013

Handhika Satrio Ramadhan, Ph.D.

I. General Information

1.	Name of Program / Study Level	:	Physics / Undergraduate
2.	Course Name	:	Classical Field Theory
3.	Course Code	:	SCFI603414
4.	Semester	:	5
5.	Credit	:	4 credits
6.	Teaching Method(s)	:	Interactive lecture
7.	Prerequisite course(s)	:	Classical Mechanics, Electromagnetic Field 1
8.	Requisite for course(s)	:	Quantum Field Theory
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; the energy-momentum tensor; Lagrangian of classical relativistic fields such as scalar fields and electromagnetic fields. The general theory of relativity, consisting of differential geometry; geodesics, and curvature; the Einstein field equations; the exterior Schwarzschild solution; the interior Schwarzschild solution; black holes; gravitational collapse; and several topics on cosmology.

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

A. CLO

It is hoped that after the completion of this course students are able to understand classical fundamental fields (electromagnetic, scalar, and gravitational) and able to apply covariant terms (Special Theory of Relativity) and the Lagrangian of continuous systems in their analysis. It is also hoped that students are able to use non-Euclidean (curved) geometry mathematical tools to analyze gravitational fields in the framework of the General Theory of Relativity, along with several phenomena related to it (exact solution of the Einstein field equations, black holes, cosmology).

B. Sub-CLO

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

1. understand Lorentz transformation,
2. identify the concepts behind tensor operations and doing them in both algebra and calculus,
3. formulate the concept of Maxwell electrodynamics using covariant terms,
4. identify the concept of the Lagrangian and the principle of least action for a continuous system,
5. derive the equation of motion from a Lagrangian for an electromagnetic field (Maxwell) and a scalar field (Klein-Gordon),
6. explain the relation between symmetry and conserved quantities in the framework of Noether's theorem,
7. understand the energy-momentum tensor and its conservation,
8. be introduced to the concept of gauge transformation,
9. formulate scalar field Lagrangians that are invariant to gauge transformations (Abelian and non-Abelian),
10. explain the equivalence between inertial mass and gravitational mass,
11. interpret gravitational fields as curvature in spacetime,
12. identify differential manifolds as mathematical tools in learning curved spacetime,
13. define tensor fields, 1-form, and differential forms on manifolds, and to do tensor calculus operations on them,
14. understand the concept of metric tensors,
15. identify Christoffel Symbols and understand why they are not a tensor,
16. formulate and use the concept of covariant derivatives as a tensor,
17. define and derive the geodesic equation on a manifold,
18. measure the intrinsic curvature of a manifold,
19. formulate the Einstein field equations for gravitational fields,

20. find the exact solution of several simple Einstein field equations (Schwarzschild, Reissner-Nordstrom, de Sitter),
21. discuss several phenomena related to the solution of the Einstein field equation (black holes, cosmology).

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	1. Lorentz transformation. 2. 4-invariance. 3. Lorentz group. 4. Tensor algebra and tensor calculus.	Lecturing	2x50 minutes	70% O, 30% F	6	Students can understand the Special Theory of Relativity quantitatively and qualitatively.	1, 2, 3, 4, 5
2	2, 3	1. 4-potential. 2. Maxwell field tensor. 3. Covariant formulation for Maxwell's equations. 4. Gauge freedom.	Lecturing	2x50 minutes	70% O, 30% F	6	Students can explain tensor analysis quantitatively.	1, 2, 3, 4, 5
3	4, 5	1. Lagrangian for continuous systems. 2. Principle of Least Action. 3. Lagrangian for scalar fields and Klein-Gordon equation of motion. 4. Maxwell field Lagrangian.	Lecturing	2x50 minutes	70% O, 30% F	6	Students can understand the use of Lagrangians and the relativistic equation of motion.	1, 3, 4
4	6	1. Symmetry and group theory. 2. Noether's Theorem. 3. Energy-momentum tensor.	Lecturing	2x50 minutes	70% O, 30% F	6	Students can understand the fundamentals of group theory, Noether's theorem, and the	1, 3

							energy-momentum tensor.	
5	7, 8, 9	1. Unitary groups. 2. Gauge invariance for Abelian and non-Abelian cases. 3. Noether's current and charge.	Lecturing	2x50 minutes	70% O, 30% F	6	Students can explain the concept of group theory and the applications of Lagrangians.	1, 3
6	10,11, 12	1. Equivalence between inertial and gravitational mass. 2. Differentiable manifolds. 3. Vector and tensor fields. 4. 1-form. 5. Differential forms. 6. Metric tensor.	Lecturing	2x50 minutes	70% O, 30% F	10	Students can explain the equivalence between inertial and gravitational mass, interpret gravitational fields as curvature in spacetime, and identify differentiable manifolds as mathematical tools in studying curved spacetime.	1, 3
7	13, 14, 15, 16	1. Christoffel Symbol. 2. Covariant derivative.	Lecturing	2x50 minutes	70% O, 30% F	10	Students can define tensor fields, 1-forms, and differential forms on manifolds, and do tensor calculus on them. They understand the concept of metric tensors. Students can identify Christoffel Symbols and understand why they are not a tensor. Students can formulate and use the concept of	1, 2, 4, 5

							covariant derivatives as a tensor.	
8	**Midterm Exam**							
9	17	1. Geodesisc equations. 2. Riemann curvature tensor. 3. Ricci tensor. 4. Scalar Ricci curvature.	Lecturing	2x50 minutes	70% O, 30% F	10	Students can define and derive the geodesic equation on a manifold.	1, 2, 4, 5
10	18	1. Relativistic gravitational field equations. 2. Gravitational fields as curvature in spacetime. 3. Einstein field equation as the equation of motion for the Einstein-Hilbert action.	Lecturing	2x50 minutes	70% O, 30% F	10	Students can measure the intrinsic curvature of a manifold.	1, 2, 4, 5
11	18	1. Metric with spherical symmetry 2. Exact exterior solution for Einstein field equations in a vacuum. 3. Birkhoff's Theorem.	Lecturing	2x50 minutes	70% O, 30% F	10	Students can measure the intrinsic curvature of a manifold.	1, 2, 4, 5
12	19, 20	1. Maxwell's equations in curved spacetime 2. Einstein-Maxwell equations 3. Exact exterior solution for charged metrics.	Lecturing	2x50 minutes	30% O, 40% E, 30% F	6	Students can formulate the Einstein field equations for gravitational fields. Students can find the exact solution of several simple Einstein	1, 2, 5

							field equations (Schwarzschild, Reissner-Nordstrom, de Sitter)	
13	21	1. Cosmological constant. 2. de Sitter space. 3. Anti-de Sitter space.	Lecturing	2x50 minutes	30% O, 40% E, 30% F	4	Students can discuss several phenomena related to the solution of the Einstein field equation (black holes, cosmology).	1, 4, 5
14	21	1. Black holes 2. Tolman-Oppenheimer-Volkoff equation for metric interiors. 3. Penrose diagram. 4. Gravitational collapse. 5. Cosmology	Lecturing	2x50 minutes	30% O, 40% E, 30% F	6	Students can discuss several phenomena related to the solution of the Einstein field equation (black holes, cosmology).	1, 4, 5
15	21	Presentation	Presentation	2x50 minutes	30% O, 40% E, 30% F	4	Students can discuss several phenomena related to the solution of the Einstein field equation (black holes, cosmology).	1, 4, 5
16	**Final Exam**							

*) O : Orientation
E : Exercise
F : Feedback

References:

1) Lewis H. Ryder, *Introduction to General Relativity*, Cambridge University Press 2009.
2) Moshe Carmeli, *Classical Fields: General Relativity and Gauge Theories*, John-Wiley and Sons 1982.
3) Lewis H. Ryder, *Quantum Field Theory*, Cambridge University Press.
4) Sean M. Carroll, *Lecture Notes on General Relativity*, http://itp.ucsb.edu/~carroll/notes, ArXiv: gr-qc/9712019.
5) Sean M. Carroll, *Spacetime and Geometry: Introduction to General Relativity*, Addison Wesley 2004.iversity

IV. Assignment Design

Week	Assignment Name	Sub-CLO	Assignment	Scope	Working Procedure	Deadline	Outcome
1	Individual Assignment 1	1	Individual Assignment	1. Lorentz group. 2. Tensor operation 3. Covariant form of Maxwell's equations	In-class and online; in groups and independently	2x50 minutes	Individual worksheet
2	Individual Assignment 2	2	Individual Assignment	1. Lagrangian and principle of least action for classical fields. 2. Scalar (Klein-Gordon) field equation of motion. 3. Energy-momentum tensor. 4. Gauge field theory.	In-class and online; in groups and independently	2x50 minutes	Individual worksheet
3	Individual Assignment 3	3	Individual Assignment	1. Vector and tensor fields. 2. 1-form and differential forms. 3. Christoffel Symbol. 4. Covariant derivatives.	In-class and online; in groups and independently	2x50 minutes	Individual worksheet
4	Individual Assignment 4	4	Individual Assignment	1. Geodesic equations. 2. Riemann curvature tensor. 3. Ricci tensor and scalar curvature.	In-class and online; in groups and independently	2x50 minutes	Individual worksheet
5	Individual Assignment 5	5	Individual Assignment	4. Schwarzschild solution. 5. Reissner-Nordstrom solution. 6. de Sitter and anti-de Sitter solution.	In-class and online; in groups and independently	2x50 minutes	Individual worksheet
6	Group Assignment	6	Group Presentation	7. Black holes. 8. Tolman-Oppenheimer-Volkoff equation. 9. Penrose diagram. 10. Gravitational collapse 11. Cosmology.	In-class and online; in groups and independently	2x50 minutes	Student PowerPoint, presentation, and individual worksheet

V. Assessment Criteria (Learning Outcome Evaluation)

Evaluation Type	**Sub-CLO**	**Assessment Type**	**Frequency**	**Evaluation Weight (%)**
Individual Assignment	1-4	Answer sheet	10	20
Group Assignment	5-6	Presentation	14	30
Midterm Exam	1-3	Answer sheet	1	30
Final Exam	4-6	Answer sheet	1	40
Total				**100**

VI. Rubric

A. Criteria of Presentation Score

Score	**Presentation Delivery**
85-90	Group is able to deliver the explanation logically, fluently, and punctual and be able to answer the questions from other students and lecturer
75-84	Group is able to deliver the explanation logically and fluently and be able to answer the questions from other students and lecturer, but be less punctual on delivering the explanation
65-74	Group is able to deliver the explanation fluently, but be less able to deliver the reasoning logic of the explanation
55-64	Group is less able to deliver the explanation fluently and punctual and be less able to deliver the reasoning logic of the explanation
<55	

B. 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