TEACHING INSTRUCTIONAL DESIGN (BRP)

COURSE

CLASSICAL FIELD THEORY

by

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UNIVERSITAS INDONESIA
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
PHYSICS UNDERGRADUATE STUDY PROGRAM

TEACHING INSTRUCTIONAL DESIGN

Course Name	Classical Field Theory	**Credit(s)**	**Prerequisite course(s)**	**Requisite for course(s)**	**Integration Between Other Courses**
Course Code	SCPH603701	3	Electromagnetic Field 1, Classical Mechanics	-	-
Relation to Curriculum	Elective Course				
Semester	5				
Lecturer(s)	Handhika Satrio Ramadhan, Ph.D				
Course Description	Classical Field Theory is an introductory course to General Relativity. In this course, students will discuss the fundamental classical fields: electromagnetic fields (vector), scalar fields, and gravitational fields (tensor). This course aims to explain fundamental classic fields, apply covariant formulations to classical field Lagrangians, along with using curved space (non-Euclidean) geometry mathematical tools to analyze gravitational fields in the framework of the General Theory of Relativity as a phenomenon of curved spacetime.				

Program Learning Outcome (PLO)	
PLO-1	Applying classical Physics concepts in general physics problems.
PLO-7	Applying the knowledge of Physics in community and practical life, as well as identifying and adapting to new things in the field of classical physics.
PLO-8	Developing and deepening the knowledge gained in the bachelor degree program in a sustainable manner, and being able to continue to the master's and doctoral education levels.
Course Learning Outcome (CLO)	
CLO-1	Students can analyze fundamental fields and their symmetry in the framework of Lagrangian formalism
CLO-2	Students can understand the unification of fundamental forces in physics in the framework of gauge theory
CLO-3	Students can analyze gravitational fields as a consequence of curvature in spacetime and apply them to problems within astrophysics
Sub-CLO(s)	
Sub-CLO 1	Explain phenomena in relativistic mechanics and electrodynamics the framework of covariant Lorentz transformation. (C3).
Sub-CLO 2	Apply the Lagrangian formalism to derive equations for fundamental classical fields. (C3)
Sub-CLO 3	Apply Abelian or non-Abelian gauge theory in particle physics and astrophysics. (C3)
Sub-CLO 4	Use differential geometry and tensor analysis in curved space to analyze gravitational phenomena as a manifestation of curvature in spacetime. (C3)
Sub-CLO 5	Find the solution to Einstein's field equation and apply it to phenomena within astrophysics and cosmology. (C3)
Study Materials	1. Lorentz transformation 2. Tensor algebra and calculus

	3. Covariant formulation of Maxwell's electromagnetic field 4. Lagrangian formulation and least action principle for continuous systems (fields) 5. Euler-Lagrange equation for Maxwell fields and scalar fields (Klein-Gordon) 6. Noether's theorem and the energy-momentum tensor 7. Gauge transformation for Abelian and non-Abelian symmetry 8. Equivalence between inertial mass and gravitational mass 9. Tensor fields and tensor calculus in curved manifolds 10. Metric tensor, the Christoffel symbol, covariant derivatives, and geodesic equations 11. Riemann curvature tensor, Ricci tensor 12. Einstein's equation for gravitational fields 13. Several exact solutions to Einstein's equation: the Schwarzschild solution, the Reissner-Nordstrom solution, the de Sitter and anti-de Sitter solution 14. Black holes
Reading List	**Required:** 1.) L. Ryder, *Introduction to General Relativity*, Cambridge University Press, 2012. 2.) S. Carroll, *Spacetime and Geometry: an Introduction to General Relativity*, Pearson Education, 2014. 3.) M. Carmeli, *Classical Fields: General Relativity and Gauge Theories*, John Wiley and Sons, 1982. 4.) M. P. Hobson, G.P. Efstathiou, dan A.N. Lasenby, General Relativity: An Introduction for Physicists, Cambridge University Press, 2006.

I. Teaching Plan

Week	Sub-CLO	Study Materials [with reference]	Teaching Method [with est. time]	Learning Experiences (*O-E-F)	Sub-CLO Achievement Indicator (*General-Specific)	Sub-CLO Weight on Course (%)
1	Sub-CLO 1	Introduction, course contract, Galileo transformation and Lorentz transformation **[Reference]** Chapter 1 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can understand that Galilean transformation is incompatible with electrodynamics, and can derive the Lorentz transformation	10%
2	Sub-CLO 1	Lorentz transformation matrix, 4-vector, scalars, vectors, and tensors, tensor algebra and calculus **[Reference]** Chapter 2 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can do Lorentz transformations; and identify scalars, vectors, and tensors based on the characteristics of their coordinate transformation	10%

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
3	Sub-CLO 1	Lorentz transformation for electromagnetic fields, Maxwell's equations in covariant form **[Reference]** Chapter 5 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can formulate the Maxwell (vector) field equation in covariant form	
4	Sub-CLO 2	Review of the Lagrangian formalism for a point particle, the Lagrangian formalism for non-relativistic and relativistic fields, scalar fields **[Reference]** Chapter 6 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can apply the least action principle for fields and derive scalar field equations from their Lagrangian	20%

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
5	Sub-CLO 2 and 3	Noether's theorem, gauge transformation, Abelian gauge theory **[Reference]** Chapter 7 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can apply Noether's theorem to derive the conserved quantities of a system due to invariance and can show the existence of the Maxwell field that is coupled to the scalar field as a consequence of gauge invariance	
6	Sub-CLO 3	Non-Abelian gauge theory **[Reference]** Chapter 8 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can derive the Yang-Mills equation and field as a consequence of invariance against non-Abelian gauge transformations	10%

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
7	Sub-CLO 4	Mass equivalence principle **[Reference]** Chapters 8 and 9 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can use the mass equivalence principle to explain the background for gravitational fields being a consequence of curvature within spacetime	30%
8	**Midterm Exam**					
9	Sub-CLO 4	Metric tensor, tensor algebra and calculus in curved space, the Christoffel symbol **[Reference]** Chapter 9 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can do algebra and calculus operations for vectors and tensors in spacetime	

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
10	Sub-CLO 4	Covariant derivatives, geodesics, parallel transport **[Reference]** Chapter 9 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can derive vector/tensor derivatives that transform covariantly in spacetime, derive geodesics in 3+1D spacetime, and can show that geodesics are the solution to parallel transport paths in curved manifolds	
11	Sub-CLO 4	Riemann curvature tensor, Ricci tensor **[Reference]** Chapter 10 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can define intrinsic curvature in curved manifolds, and derive testing the curvature of the spacetime of a metric using the Riemann tensor and Ricci tensor	

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
12	Sub-CLO 5	Einstein field equations, Einstein-Hilbert action **[Reference]** Chapter 10 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can derive the Einstein field equations as the modern gravitational field equation using the bottom-up and top-down approach (from the first principle)	30%
13	Sub-CLO 5	Schwarzschild solution **[Reference]** Chapter 11 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can find exact spacetime solutions around massive objects with spherical symmetry	

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
14	Sub-CLO 5	Schwarzschild metric geodesic, perihelion precession, gravitational lensing around massive stars **[Reference]** Chapter 11 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%) **Feedback:** Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)	Students can derive and find the geodesic solution for the Schwarzschild metric and apply it to calculate the orbital precession of Mercury and the lensing angle around massive stars	
15	Sub-CLO 5	Black holes **[Reference]** Chapter 11 of the required textbook	*Asynchronous* via video recording uploaded to YouTube and EMAS UI (individual learning and discussion forum) *Synchronous* via MS Teams	**Orientation:** Students see files, watch videos, or use chatrooms in EMAS (30%) **Exercise:** Students discuss via MS Teams or EMAS chatrooms and do independent literature review for unclear concepts (50%)	Students can analyze the null geodesic of a Schwarzschild metric to show the existence of black holes	

				Feedback: Lecturer responds to discussions in MS Teams or EMAS chatrooms (20%)		
16	**Final Exam**					

II. Assignment Design

Week	Assignment Name	Sub-CLOs	Assignment	Scope	Working Procedure	Deadline	Outcome
2	Individual Assignment 1	1	Essay	Lorentz transformation and relativistic mechanics	Individual Homework	1 week	.PDF file
3	Individual Assignment 2	1	Essay	Covariant Maxwell equations	Individual Homework	1 week	.PDF file
5	Individual Assignment 3	2	Essay	Euler-Lagrange equation and Noether's theorem for Maxwell and scalar fields	Individual Homework	1 week	.PDF file
6	Individual Assignment 4	3	Essay	Euler-Lagrange equation for pure Yang-Mills and Yang-Mills-Higgs fields	Individual Homework	1 week	.PDF file
10	Individual Assignment 5	4	Essay	Christoffel symbols, covariant derivatives, and geodesics	Individual Homework	1 week	.PDF file
11	Individual Assignment 6	4	Essay	Curvature tensor	Individual Homework	1 week	.PDF file
12	Individual Assignment 7	5	Essay	Birkhoff's theorem for the Schwarzschild solution	Individual Homework	1 week	.PDF file
14	Individual Assignment 8	5	Essay	Phenomenological aspects of the Schwarzschild solution geodesic	Individual Homework	1 week	.PDF file

III. Assessment Criteria (Learning Outcome Evaluation)

Evaluation Type	Sub-CLO	Assessment Type	Frequency	Evaluation Weight (%)
Individual Assignment (Homework)	1-7	Written exam submitted via email	8x	40%
Midterm Exam	1-3	Written exam submitted via email	1x	30%
Final Exam	4-5	Written exam submitted via email	1x	30%
			Total:	100%

IV. Rubric(s)

This rubric is used as a guideline for assessing or giving levels of student performance results. a rubric usually consists of assessment criteria that include the dimensions / aspects that are assessed based on indicators of learning achievement. This assessment rubric is useful for clarifying the basics and aspects of the assessment so that students and lecturers can be guided by the same thing regarding the expected performance demands. Lecturers can choose the type of rubric according to the assessment given.

A. Conversion of the student's final score

Score	Grade	Equivalent
85 - 100	A	4.00
80 - < 85	A-	3.70
75 - < 80	B+	3.30
70 - < 75	B	3.00
65 - < 70	B-	2.70
60 - < 65	C+	2.30
55 - < 60	C	2.00
40 - < 50	D	1.00
< 40	E	0.00

B. Assessment rubric

Criteria	80-100	65-80	50-65	0-50
Mathematical Model for Problems	Student constructed a mathematical model that accounts for all related mechanical laws and system symmetry/parameters.	Student constructed a mathematical model that accounts for all related mechanical laws but failed to account for system symmetry/parameters.	Student constructed a mathematical model but failed to account for all related mechanical laws or system symmetry/parameters.	Student did not know what to do.

Solution to Equations of Motion	Based on the constructed mathematical model, student was able to find the solution to the system equation of motion (typically differential equations) by using mathematical techniques learned in the Mathematical Methods in Physics course and correctly set the boundary conditions for the system.	Based on the constructed mathematical model, student was able to find the solution to the system equation of motion (typically differential equations) by using mathematical techniques learned in the Mathematical Methods in Physics course but did not correctly set the boundary conditions for the system.	Student tried to find the solution to the system equation of motion. Solution is incorrect.	Student did not know what to do.
Physical Interpretation	Student was able to interpret obtained mathematical solutions into something physical	Student was able to interpret obtained mathematical solutions into something physical, but their interpretation was imprecise	Student was unable to interpret obtained mathematical solutions into something physical	Student was unable to explain quantum characteristics