Form: Course Syllabus	**Form Number**	EXC-01-02-02A
	Issue Number and Date	2/3/24/2022/2963 05/12/2022
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1.	**Course Title**	Quantum Field Theory-1
2.	**Course Number**	0332958
3.	**Credit Hours (Theory, Practical)**	(3,0)
	Contact Hours (Theory, Practical)	(3,0)
4.	**Prerequisites/ Corequisites**	0302959
5.	**Program Title**	
6.	**Program Code**	Ph.D. in Physics
7.	**School/ Center**	Science
8.	**Department**	Physics
9.	**Course Level**	PhD
10.	**Year of Study and Semester (s)**	2015, Spring
11.	**Other Department(s) Involved in Teaching the Course**	
12.	**Main Learning Language**	
13.	**Learning Types**	☒Face to face learning ☐Blended ☐Fully online
14.	**Online Platforms(s)**	☐Moodle ☐Microsoft Teams
15.	**Issuing Date**	2/6/2015
16.	**Revision Date**	28/1/2025

17. Course Coordinator:

Name: Mohammad Hussein	Contact hours: Sunday, Tuesday 13.30-14.30
Office number: 08	Phone number: 22023
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18. Other Instructors:

Name:

Office number:

Phone number:

Email:

Contact hours:

Name:

Office number:

Phone number:

Email:

Contact hours:

19. Course Description:

This course serves as an introductory exploration of quantum field theory (QFT). QFT examines systems where both special relativity and quantum mechanics play significant roles. Participants will understand the reasons why QFT is the ideal framework for elucidating a wide variety of phenomena observed in experiments conducted thus far. Students will also build a toolkit of highly advanced techniques, such as Wick's theorem, Noether's theorem, Ward-Takahashi identity, path integrals, renormalization and regularization, and symmetry analysis.

It is crucial to highlight that this course is designed for third-year graduate students who have successfully completed the advanced quantum mechanics-3 course, PHY 0302959.

20. Program Intended Learning Outcomes: (To be used in designing the matrix linking the intended learning outcomes of the course with the intended learning outcomes of the program)

1. To be able to demonstrate an advanced and comprehensive understanding of core physics concepts and specialized knowledge in a chosen field of research, contributing to the frontier of physics.
2. To be able to develop and execute independent, original research projects that address complex scientific problems, advancing theoretical and experimental physics.
3. To be able to apply advanced mathematical and computational techniques to analyze complex physical phenomena and critically evaluate scientific literature and experimental results.
4. To be able to effectively communicate complex physics concepts, research findings, and their significance through academic writing, presentations, and public outreach.

5. To be able to adhere to high ethical standards and professional responsibility in conducting research, including data integrity, ethical treatment of subjects, and the responsible use of resources.
6. To be able to demonstrate leadership and collaborative skills within multidisciplinary teams, contributing to the development of new scientific knowledge and promoting knowledge-sharing across disciplines.
7. To be able to cultivate the ability to adapt to new scientific advancements and continuously engage in professional development to contribute to innovation in the field of physics.
8. To be able to master experimental and computational techniques relevant to the research field, demonstrating competency in operating and developing specialized physics instrumentation and software.

21. Course Intended Learning Outcomes: (Upon completion of the course, the student will be able to achieve the following intended learning outcomes)

1. Review the basic concepts in classical mechanics (e.g., Lagrangian, Hamiltonian, scattering cross section, Poisson brackets).
2. Review the basic concepts in special relativity (e.g., 4-vector, Minkowski metric, Lorentz group).
3. Review the basic concepts in classical field theory (e.g., electromagnetism, dispersion relation, stress energy tensor).
4. Review the basic concepts in quantum mechanics (e.g., canonical quantization, harmonic oscillator, spin/helicity, normal ordering, partition function, path integral).
5. Discuss the quantization of scalar fields: Klein-Gordon equation, creation and annihilation operators, particles and antiparticles, causality and propagators, pole prescription.
6. Discuss the quantization of spin-$\frac{1}{2}$ fields: Dirac equation, gamma matrices, spinor wavefunctions (u and v), Feynman propagator, projection operators for positive and negative energy states, helicity projection operators, chirality projection operators, spin projection operators.
7. Discuss the generalities of the S-matrix theory and Wick’s theorem: Dyson's Formula, a master formula for $n \to m$-particle S-matrix elements.
8. Determine Feynman amplitude of the S-matrix element for spin-0 and spin-$\frac{1}{2}$ fields: Feynman rules, virtual particles.
9. Use Feynman diagrams to calculate decays rates and scattering cross sections for some processes: decay of a scalar into a fermion-antifermion pair, and 2-to-2 scattering.
10. The quantization of the spin-1 fields, with special reference to the photon: modifying the classical EM field, and addressing the 4 polarization states and their physical meaning.
11. Quantum Electrodynamics (QED): the crucial concept of gauge invariance, detailed derivations of important scattering processes at their Leading Orders (LO) in perturbation theory, such as:
    11.1 electron-electron scattering: $e^- + e^- \to e^- + e^-$
    11.2 electron-positron scattering: $e^- + e^+ \to e^- + e^+$ (Bhabha scattering)

11.3 $e^- + e^+ \rightarrow \mu^- + \mu^+$
11.4 electron-photon scattering: $e^- + \gamma \rightarrow e^- + \gamma$ (Compton scattering)
12. Employ discrete symmetries to offer significant insights into the structure of the Lagrangian while determining higher-order corrections (NLO, NNLO) for a specific interaction: Parity (P), Time reversal (T), Charge conjugation (C), CP combination, and CPT combination.
13. Explain essential concepts of renormalization, focusing on QED as the illustrative interacting theory: loops, infra-red divergence, ultra-violet divergence, cutoff regularization, dimensional regularization schemes (MS and $\overline{\text{MS}}$), counter terms, subtraction scale (μ), Ward-Takahashi identity, and renormalization of electric charge and mass.

Course ILOs	**The learning levels to be achieved**					
	Remembering	**Understanding**	**Applying**	**Analysing**	**evaluating**	**Creating**
1		✓	✓	✓		
2		✓	✓	✓		
3		✓	✓	✓		
4		✓	✓	✓		
5		✓	✓	✓		
6		✓	✓	✓		
7		✓	✓	✓		
8		✓	✓	✓		
9		✓	✓	✓		
10		✓	✓	✓		
11		✓	✓	✓		
12		✓	✓	✓		
13		✓	✓	✓		

2٢. The matrix linking the intended learning outcomes of the course with the intended learning outcomes of the program:

Program ILOs / Course ILOs	ILO (1)	ILO (2)	ILO (3)	ILO (4)	ILO (5)	ILO (6)	ILO (7)	ILO (8)
1	✓	✓	✓	✓			✓	
2	✓	✓	✓	✓			✓	
3	✓	✓	✓	✓			✓	
4	✓	✓	✓	✓			✓	
5	✓	✓	✓	✓			✓	
6	✓	✓	✓	✓			✓	
7	✓	✓	✓	✓			✓	
8	✓	✓	✓	✓			✓	
9	✓	✓	✓	✓			✓	
1	✓	✓	✓	✓			✓	
11	✓	✓	✓	✓			✓	
12	✓	✓	✓	✓			✓	
13	✓	✓	✓	✓			✓	

2٣. Topic Outline and Schedule:

Week	Lecture	Topic	ILO/s Linked to the Topic	Learning Types (Face to Face/ Blended/ Fully Online)	Platform Used	Synchronous / Asynchronous Lecturing	Evaluation Methods	Learning Resources
1	1.1	-Review the basic concepts in classical mechanics (e.g., Lagrangian, Hamiltonian, scattering cross section, Poisson brackets).	1,2					
	1.2							
	1.3							

		-Review the basic concepts in special relativity (e.g., 4-vector, Minkowski metric, Lorentz group).						
2	2.1 2.2 2.3	-Review the basic concepts in classical field theory (e.g., electromagnetism, dispersion relation, stress energy tensor). -Review the basic concepts in quantum mechanics (e.g., canonical quantization, harmonic oscillator, spin/helicity, normal ordering, partition function, path integral).	3,4					
3	3.1 3.2 3.3	Discuss the quantization of scalar fields: Klein-Gordon equation, creation and annihilation operators, particles and antiparticles, causality and propagators, pole prescription.	5					
4	4.1 4.2 4.3	Discuss the quantization of spin-1/2 fields: Dirac equation, gamma matrices, spinor wavefunctions (*u* and *v*), Feynman propagator, projection operators for positive and negative energy states, helicity projection operators, chirality projection operators, spin projection operators.	6					
5	5.1 5.2 5.3	-Discuss the quantization of spin-1/2 fields: Dirac equation, gamma matrices, spinor wavefunctions (*u* and *v*), Feynman propagator, projection operators for positive and negative energy states, helicity projection operators, chirality projection operators, spin projection operators. -Discuss the generalities of the *S*-matrix theory and Wick's theorem: Dyson's Formula, a master formula for n→m-particle *S*-matrix elements.	6,7					
6	6.1 6.2 6.3	Determine Feynman amplitude of the *S*-matrix element for spin-0 and spin-1/2 fields: Feynman rules, virtual particles.	8					
7	7.1 7.2 7.3	Use Feynman diagrams to calculate decays rates and scattering cross sections for some processes: decay of a scalar into a fermion-antifermion pair, and 2-to-2 scattering.	9					
8	8.1 8.2	The quantization of the spin-1 fields, with special reference to the photon: modifying the	10					

	8.3	classical EM field, and addressing the 4 polarization states and their physical meaning.						
9	9.1	Quantum Electrodynamics (QED): the crucial concept of gauge invariance, detailed derivations of important scattering processes at their Leading Orders (LO) in perturbation theory, such as: 11.1 electron-electron scattering: $e^- + e^- \rightarrow e^- + e^-$	11.1					
	9.2							
	9.3							
10	10.1	Quantum Electrodynamics (QED): the crucial concept of gauge invariance, detailed derivations of important scattering processes at their Leading Orders (LO) in perturbation theory, such as: 11.2 electron-positron scattering: $e^- + e^+ \rightarrow e^- + e^+$ (Bhabha scattering)	11.2					
	10.2							
	10.3							
11	11.1	Quantum Electrodynamics (QED): the crucial concept of gauge invariance, detailed derivations of important scattering processes at their Leading Orders (LO) in perturbation theory, such as: 11.3 $e^- + e^+ \rightarrow \mu^- + \mu^+$	11.3					
	11.2							
	11.3							
12	12.1	Quantum Electrodynamics (QED): the crucial concept of gauge invariance, detailed derivations of important scattering processes at their Leading Orders (LO) in perturbation theory, such as: 11.4 electron-photon scattering: $e^- + \gamma \rightarrow e^- + \gamma$ (Compton scattering)	11.4					
	12.2							
	12.3							
13	13.1	Employ discrete symmetries to offer significant insights into the structure of the Lagrangian while determining higher-order corrections (NLO, NNLO) for a specific interaction: Parity (P), Time reversal (T), Charge conjugation (C), CP combination, and CPT combination.	12					
	13.2							
	13.3							
14	14.1	Explain essential concepts of renormalization, focusing on QED as the illustrative interacting theory: loops, infra-red divergence, ultra-violet divergence, cutoff regularization, dimensional regularization schemes (MS and $\overline{\text{MS}}$), counter terms, subtraction scale (μ), Ward-Takahashi	13					
	14.2							
	14.3							

		identity, and renormalization of electric charge and mass.						
15	15.1	Explain essential concepts of renormalization, focusing on QED as the illustrative interacting theory: loops, infra-red divergence, ultra-violet divergence, cutoff regularization, dimensional regularization schemes (MS and $\overline{\text{MS}}$), counter terms, subtraction scale (μ), Ward-Takahashi identity, and renormalization of electric charge and mass.	13					
	15.2							
	15.3							

2٤. Evaluation Methods:

Opportunities to demonstrate achievement of the ILOs are provided through the following assessment methods and requirements:

Evaluation Activity	Mark	Topic(s)	ILO/s Linked to the Evaluation activity	Period (Week)	Platform
First Exam	30		1,2,3,4,5,6,7,8,9	8	On campus
Second Exam	30		10,11	12	On campus
Final Exam	40		1,2,3,4,5,6,7,8,9,10,11,12, 13	15	On campus

2٥. Course Requirements:

(e.g.: students should have a computer, internet connection, webcam, account on a specific software/platform…etc.):

N/A

2٦. Course Policies:

A- Attendance policies: According to JU by-laws.

B- Absences from exams and submitting assignments on time: According to JU by-laws.

C- Health and safety procedures: N/A

D- Honesty policy regarding cheating, plagiarism, misbehavior: According to JU by-laws.

E- Grading policy: According to JU by-laws.

F- Available university services that support achievement in the course: N/A

2٧. References:

A- Required book(s), assigned reading and audio-visuals:

Text: An Introduction to Quantum Field Theory by M. Peskin & D. Schroeder, 1st edition, Advanced Book Program 1995, ISBN 0-201-50397-2.

B- Recommended books, materials, and media:

References: Suggested titles include, but are not limited to:
-Quantum Field Theory, by M. Srednicki, 1st edition, Cambridge University Press 2007, ISBN 978-0521864497.
-Quantum Field Theory in a Nutshell, by A. Zee, 2nd edition, Princeton University Press 2010, ISBN 978-0691140346.
-Quantum Field Theory and the Standard Model, by M. Schwartz, 1st edition, Cambridge University Press 2013,
ISBN 978-1107034730.
-Lectures on Quantum Field Theory by D. Tong: the lecture notes are available online: http://www.damtp.cam.ac.uk/user/tong/qft.html.

2٨. Additional information:

Name of the Instructor or the Course Coordinator:	Signature:	Date:
Mohammad Hussein		28/1/2025
Name of the Head of Quality Assurance Committee/ Department	Signature:	Date:
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Name of the Head of Department	Signature:	Date:
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Name of the Head of Quality Assurance Committee/ School or Center	Signature:	Date:
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Name of the Dean or the Director	Signature:	Date:
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