Syllabus template

Semester: VII	
Programme : Physics	
Course : Relativistic Quantum Mechanics & Elementary Particle Physics	
Paper code: C4PH230731T	**Credits: 2+2**
Hours/week : 4	
Category: Core/MDC/SEC/VAC : Major	
Theory / Practical / Composite : Theory	
No of Modules : 2	

Course Overview:

The course offers a comprehensive curriculum for a seventh-semester undergraduate course focused on Relativistic Quantum Mechanics. The syllabus begins with foundational concepts like natural units and Lorentz symmetry before addressing the issues raised by the Klein-Gordon equation. A significant portion of the studies focuses on the Dirac equation, exploring the intrinsic properties of electrons such as spin and magnetic moments. Students will also examine mathematical transformations and the behavior of particles under various physical symmetries. Finally, the course introduces Feynman diagrams as a tool to calculate interactions during particle decay and scattering events.

Course Outcomes (COs) for Relativistic Quantum Mechanics

1. **Utilize natural units and Lorentz symmetry, including four-vector notation, to describe relativistic physical systems**
2. **Analyze the Klein-Gordon equation, specifically understanding the Yukawa Potential and addressing the theoretical challenges associated with negative energy states and negative probability density**
3. **Apply the Dirac equation in its covariant form, including the derivation of adjoint equations, plane wave solutions, and the use of momentum space spinors**
4. **Evaluate the relativistic properties of the electron, such as its spin, magnetic moment, helicity, and chirality, while performing non-relativistic reductions**
5. **Determine the transformation properties of spinors and bilinear covariants under parity, charge conjugation, and both infinitesimal and standard Lorentz transformations**

Course Outcomes (COs) for Elementary Particle Physics

1. **Learns about cosmic rays and it's implications for Astro-particle physics**
2. **Understand Elementary particle facts, strangeness and isospin**
3. **Gets acquainted with the Quark model of hadrons**
4. **Is exposed to the theory of Electroweak interaction and the idea of spontaneous symmetry breaking**

5. **Becomes acquainted with the idea of neutrino oscillations**				
Prerequisites: ***Quantum Mechanics, Relativity Theory, The student is expected to have some background in quantum mechanics and electromagnetic theory.***				
SYLLABUS				
UNIT/Module	**CONTENT**	**HOURS or NUMBER OF CLASSES**	**CO Map ping**	**COGNITIVE LEVEL**
I.	**A) Essentials:** Natural units and their use; Noether's theorem; Elements of Lorentz symmetry and the four vector notation.	**4L**	**CO1**	K1, K3, K5
	B) Klein-Gordon equation: Problem with negative energy states and negative probability density.	**4L**	**CO2**	K2, K5
	C) Dirac equation I: Factorization of the relativistic energy momentum relation; alpha and beta matrices: properties, covariant form, adjoint equation, plane wave solution. Feynmann-Stuckelberg interpretation of negative energy states	**6L**	**CO3**	K3, K4, K5
	D) Dirac Equation II: Momentum space spinors, spin and magnetic moment of the electron, non-relativistic reduction, helicity and chirality, properties of gamma matrices, charge conjugation, normalization and completeness of spinors, Lorentz transformation of the Dirac equation, bilinear covariants and their transformations under parity and infinitesimal Lorentz transformation, Weyl representation and chirality projection operators.	**10L**	**CO4, CO5**	K2, K4, K6

II.	**A) Elementary Particles:** Historical Perspective: Cosmic rays. Fundamental interactions: mediators, leptons, quarks and hadrons	**4L**	**CO1**	K1, K2
	B) Symmetry in Elementary Particles: Discrete and Continuous Symmetries; Intrinsic Parity and Charge Conjugation Symmetries. Strange Particles, Mesons and Hyperons, Isospin and Parity, G-parity, Neutrinos – Reines' and Cowan's experiment, Strangeness oscillations (K0 - system)	**6L**	**CO2**	K4
	C) The Quark Model (1964) Color hypothesis, elementary ideas about the strong interaction(QCD), elementary calculation of color factors, discovery of heavier quarks and leptons	**6L**	**CO3**	K4, K6
	D) Elementary ideas of weak interaction and electroweak unification	**5L**	**CO4**	K1, K2
	E) Neutrino oscillation – elementary idea with a simple derivation of the transition probabilities in terms of the square of the mass difference	**3L**	**CO5**	K3, K4
Text Books (For Both sections)				
1. Quarks and Leptons by F. Halzen and A. Martin (John Wiley)				
2. Nuclear and Particle Physics: An Introduction by Brian Martin (Wiley)				
3. Particles and Nuclei by Povh, Rith and Scholz (Springer)				
4. Elementary Particles by David J. Griffiths (John Wiley)				
5. Astroparticle Physics by Claus Grupen (Springer)				
6. Particle Astrophysics by Donald H. Perkins (Oxford)				
Suggested readings				

1. **Quantum Field Theory by Franz Mandl and Graham Shaw:**
2. **An Introductory Course of Particle Physics by Palash Baran Pal**
3. **A first book of QFT by Amitabha Lahiri**
4. **Introduction to Elementary Particle Physics by A. Bettini (Cambridge)**
Web Resources (OER)
1. **NIKHEF : Particle Physics 1:**   **https://www.nikhef.nl/~wouterh/teaching/PP1/LectureNotes2012.pdf**
2. **David Tong: Lectures on Quantum Field Theory (University of Cambridge):**
3. **MIT OpenCourseWare - Relativistic Quantum Theory (8.324)**
4. **OER QFT For Non Specialists:**   **https://epx.phys.tohoku.ac.jp/~yhitoshi/particleweb/particle.html**
5. **Alessandro De Angelis and Mario Pimenta : Introduction to Astropaticle Physics : Multimessenger Astrophysics with a Particle Physics Toolbox -**   **https://agenda.infn.it/event/15232/attachments/20619/23398/bookapmin.pdf**
Evaluation : Theory CIA: 30 (2x10 + 5/assgn.+ 5/attn.). Semester Exam: 35
Paper Structure for Theory Semester Exam Module : For each 35 mark module,   15 Marks from 3 marks questions (5 out of 7)   20 Marks from 10 marks questions (2 out of 3)

Course outcomes (COs) and Cognitive Level Mapping for RQM

COs	CO Description	Cognitive levels
CO1	Apply natural units and Lorentz symmetry using four-vector notation to characterize and model relativistic physical systems.	K1, K3, K5
CO2	Explain the foundations of the Klein-Gordon equation, specifically the Yukawa Potential and the conceptual challenges involving negative energy states and negative probability density.	K2, K5
CO3	Derive solutions for the Dirac equation in its covariant form, including adjoint equations, plane wave solutions, and the use of momentum space spinors.	K3, K4, K5
CO4	Analyze the relativistic properties of the electron, such as spin, magnetic moment, helicity, and chirality, while utilizing non-relativistic reduction methods and gamma matrices.	K2, K4, K6
CO5	Determine the transformation properties of spinors and bilinear covariants under parity, charge conjugation, and both standard and infinitesimal Lorentz transformations.	K2, K4, K6
CO6	Construct and calculate Feynman diagrams for specific processes, such as spinless electron-electron scattering, to determine resulting matrix elements and scattering cross sections.	K3, K4, K6

Course outcomes (COs) and Cognitive Level Mapping for Particle Physics

COs	CO Description	Cognitive levels
CO1	Learns about cosmic rays and it's implications for Astro-particle physics	K1, K2
CO2	Understand Elementary particle facts, strangeness and isospin	K1, K2, K4, K6
CO3	Gets acquainted with the Quark model of hadrons	K3, K4
CO4	Is exposed to the theory of Electroweak interaction and the idea of spontaneous symmetry breaking	K1, K2
CO5	Becomes acquainted with the idea of neutrino oscillations	K1,K2, K3, K4