PHY-361 Special Relativity

Credit Hours: 3-0

Pre-requisite: None

Course Objectives:

The first objective of the course is to introduce the Einstein's Special Theory of Relativity, which gives totally different perspective of space and time by connecting both entities to a single entity called the "Spacetime". The very notion of space and time changes in this theory as compared to the Newton's perspective of absolute space and absolute time. With this new notion of spacetime, in this course, we introduce the relativistic kinematics and relativistic dynamics, and introduce the geometrical essence of Special Relativity by using the four-vector formulism. The second objective is to introduce Electrodynamics in covariant form. For this purpose, we use the relativistic kinematics and dynamics to write down the Maxwell equations in covariant form. In addition to this, we introduce the four-vector formulism for Maxwell equations by defining the electromagnetic field tensor. We also discuss the dynamics of relativistic particles and electromagnetic fields. Finally, we introduce the relativistic Lagrangian and Hamiltonian formulism for scalar and vector fields. Specifically, we discuss the relativistic Lagrangian and Hamiltonians for electromagnetic fields and finally, we finish the course by introducing the canonical and symmetric stress tensors for electromagnetic fields.

Core Contents:

Michelson Morley Experiment, Postulates of Special Relativity, Coordinate Transformations, Vector and Tensor Transformations, Four Vector Formalism, Relativistic Kinematics, Covariant Form of Maxwell Equations, Relativistic Lagrangian and Hamiltonian Formalism of Fields: Scalar and Vector fields, Canonical Stress Tensor, Symmetries and Conservation laws.

Detailed Course Contents:

Newton's Perspective of Space and Time, Michelson Morley Experiment and the Ether, Basic postulates of Special Relativity, Basic Concepts: (Events, Frame of References, Observers, and etc.], Galilean Transformations and Lorentz Transformations, Derivation of Lorentz Transformation, Time Dilation, Length Contraction, Relativity of Simultaneity, Doppler Effect, Twin Paradox, Velocity Transformations, Minkowski Spacetime, Spacetime Diagrams, Light Cone, Causality, Spacetime Separation and Minkowski Metric, Vectors and Tensors, and their Transformations, Covariant and Contravariant Tensors, Rank of a Tensor, Symmetric and Antisymmetric Tensors, Metric Tensor, Application of Transformations from Cartesian to Polar and Spherical Coordinates, Groups, Lorentz groups, Poincare groups, Four Vector Formalism, Four Vector formalism of Lorentz Transformation, Invariants and Physical Laws, Relativistic Momentum, Relativistic Kinetic energy, Total Relativistic Energy and Mass Energy, Four-Momentum, The Energy-Momentum Relation, The Conservation of Energy and Momentum, Four Force, Compton Scattering, Magnetism as Relativistic Phenomena, Lorentz Transformations of Electromagnetic Field, Construction of Electromagnetic Field Tensor, Covariant Form of Maxwell Equations, Relativistic Potentials, Gauge Transformation of Electromagnetic Field, Relativistic Lagrangian and Hamiltonian Formalism (for a Single Particle and a Field), Lagrangian and Hamiltonian Formalism for Relativistic Charged Particle in the Presence of Electromagnetic Field, Lagrangian and Hamiltonian for Electromagnetic Field, Proca Lagrangian, Canonical and Symmetric Stress Tensors and Conservation Laws. Solution of Wave Equation in Covariant form.

Course Outcomes:

Students will be able to understand the four-vector formalism in general

Students will be able to understand the covariant form of Maxwell equations

This course will be very useful in various areas of physics, such as General Relativity, Particle Physics and Condensed Matter Physics.

Textbooks:

Robert J. A. Lambourne, Relativity, Gravitation and Cosmology, Cambridge University Press, 2010. (referred as RL)

David J. Griffiths, Introduction to Electrodynamics, Pearson India Education Services Private Limited, 2015. (referred as DG)

John David Jackson, Classical Electrodynamics, John Wiley & Sons, 1999. (referred as JDJ)

Reference Books:

Asghar Qadir, An Introduction to Special Relativity, World Scientific, 1989. (Referred as AQ)

Bernard F. Schutz, A first course in General Relativity, Cambridge University Press

Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler, Gravitation, W. H. Freeman and Company, Princeton University Press.
Steven Weinberg (SW), Gravitation and Cosmology, John Wiley and Sons, 1972.

Weekly Breakdown		
Week	Section	Topics
1	RL 1.1, 1.2	Newton's Perspective of Space and Time, Michelson Morley Experiment and the Ether, Basic postulates of Special Relativity, Basic Concepts: (Events, Frame of References, Observers, etc.), Galilean Transformations and Lorentz Transformations, Derivation of Lorentz Transformation
2	RL 1.3	Time Dilation, Length Contraction, Relativity of Simultaneity, Doppler Effect, Twin Paradox, Velocity Transformations
3	RL 1.4	Minkowski spacetime, Spacetime diagrams, Light Cone, Causality, Spacetime separation and Minkowski metric
4	Handouts	Vectors and Tensors, and their Transformations, Covariant and Contravariant Tensors, Rank of a Tensor, Symmetric and Antisymmetric Tensors, Metric Tensor, Application of Transformations from Cartesian to Polar and Spherical Coordinates
5	Handouts	Groups, Lorentz groups, Poincare groups
6	RL 2.2.1-2.2.3	Four Vector Formalism, Four Vector formalism of Lorentz Transformation, Invariants and Physical Laws, Relativistic Momentum, Relativistic Kinetic energy, Total Relativistic Energy and Mass Energy
7	RL 2.2.4-2.2.8	Four-Momentum, The Energy-Momentum Relation, The Conservation of Energy and Momentum, Four Force, Compton Scattering
8	DG 12.3.1-12.3.2	Magnetism as Relativistic Phenomena, Lorentz Transformations of Electromagnetic Fields
9	DG 12.3.3 12.3.4	Construction of Electromagnetic Field Tensor, Covariant Form of Maxwell Equations
10	DG 12.3.5	Relativistic Potentials, Gauge Transformation of Electromagnetic Field
11	Handouts JDJ 12.1	Relativistic Lagrangian and Hamiltonian Formalism (for a Single Particle and a Scalar Field)

12	JDJ 12.1	Lagrangian and Hamiltonian Formalism for Relativistic Charged particle in the Presence of Electromagnetic Field
13	JDJ 12.7, 12.8	Lagrangian and Hamiltonian for Electromagnetic Field, Proca Lagrangian,
14	JDJ 12.10	Canonical and Symmeteric Stress Tensors and Conservation Laws
15	JDJ 12.11	Noether's Theorem, Solution of Wave Equation in Covariant form