# PHY-315 Electrodynamics and Special Relativity

**Credit Hours:** 3-0

**Pre-requisite:** PHY-306 Electromagnetic Theory

**Course Objectives:**

It is an undergraduate core course and is an extension of core course electrodynamics I. It aims to make students understand electromagnetic waves, wave guides and electromagnetic radiation. The first objective of this course is also 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.

**Core Contents:**

The wave equation, Electromagnetic waves in conductors and non-conducting media, dispersion, wave guides, electromagnetic resonators, waves in complex media and plasma, scalar and vector potential, electromagnetic radiations. Postulates of Special Relativity, Coordinate Transformations, Vector and Tensor Transformations, Four Vector Formalism, Relativistic Kinematics, Covariant Form of Maxwell Equations, Lorentz transformations of electric and magnetic fields.

**Detailed Course Contents:**

E electromagnetic waves: the wave equation, sinusoidal waves, reflection and transmission, polarization, EM waves in vacuum: the wave equation for E and B, monochromatic plane waves, energy and momentum in electromagnetic waves, EM waves in matter, propagation in linear media, reflection and transmission at normal and oblique incidence, EM waves in conductors, reflection at conducting surface, the frequency dependence of permittivity, wave guides, transverse electric waves in rectangular wave guide, the coaxial transmission line, potentials and fields: scalar and vector potentials, gauge transformations, Coulomb gauge and Lorentz gauge, continuous distributions: retarded potentials, Jefimenko's equations, point charges, Lienard-Wiechert potentials, the field of a moving point charge, radiation, electric dipole radiation, magnetic dipole radiations, radiation from an arbitrary source, power radiation by a point charge, radiation reaction, the physical basis of the radiation reaction.

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, 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.

**Course Outcomes:** At the end of the course, students will be able to understand

- the electromagnetic waves and their transmission in various media
- the electromagnetic waves in vacuum and matter and phenomena in wave guides
- the concept of vector potential and gauge transformations
- the radiations by point charges, electric dipoles, magnetic dipoles and arbitrary source.
- the four-vector formalism in general
- the covariant form of Maxwell equations
- the Lorentz transformation of electric and magnetic fields

**Textbooks:**

1. David J. Griffiths, Introduction to Electrodynamics, Pearson India Education Services Private Limited, 2015. (referred as DG)
2. Robert J. A. Lambourne, Relativity, Gravitation and Cosmology, Cambridge University Press, 2010. (referred as RL)

**Reference Books:**

1. F. J. Milford, R W. Christy, Foundations of Electromagnetic theory, 4th edition, Addison-Wesley, 2008.
2. Asghar Qadir, An Introduction to Special Relativity, World Scientific, 1989. (referred as AQ)
3. Bernard F. Schutz, A first course in General Relativity, Cambridge University Press
4. Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler, Gravitation, W. H. Freeman and Company, Princeton University Press
5. Steven Weinberg (SW), Gravitation and Cosmology, John Wiley and Sons, 1972.

| **Weekly Breakdown** | | |
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| ***Week*** | ***Section*** | ***Topics*** |
| **1** | DG 9.1 | Electromagnetic Waves: The wave equation, Sinusoidal waves, reflection and transmission, Polarization |
| **2** | DG 9.2, 9.3 | EM waves in vacuum: the wave equation for E and B, monochromatic plane waves, energy and momentum in electromagnetic waves, EM waves in matter, propagation in linear media, reflection and transmission at normal and oblique incidence |
| **3** | DG 9.4, 9.5 | EM waves in conductors, reflection at conducting surface, the frequency dependence of permittivity, wave guides, transverse electric waves in rectangular wave guide, the coaxial transmission line |
| **4** | DG 10.1 | Potentials and fields: Scalar and vector potentials, gauge transformations, Coulomb gauge and Lorentz gauge |

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| **5** | DG 10.2 | Continuous distributions: retarded potentials, Jefimenko's equations |
| **6** | DG 10.3 | Point charges, Lienard-Wiechert potentials, the field of a moving point charge |
| **7** | DG 11.1 | Radiation, electric dipole radiation, magnetic dipole radiations, radiation from an arbitrary source |
| **8** | DG 11.2 | Power radiation by a point charge, radiation reaction, the physical basis of the radiation reaction |
| **9** | RL 1.2, 1.3 | Derivation of Lorentz Transformation, Time Dilation, Length Contraction, Relativity of Simultaneity, Doppler Effect, Twin Paradox, Velocity Transformations |
| **10** | RL 1.4 | Minkowski spacetime, Spacetime diagrams, Light Cone, Causality, Spacetime separation and Minkowski metric |
| **11** | 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 |
| **12** | 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 |
| **13** | RL 2.2.4-2.2.8 | Four-Momentum, The Energy-Momentum Relation, The Conservation of Energy and Momentum, Four Force, Compton Scattering |
| **14** | DG 12.3.1-12.3.2 | Magnetism as Relativistic Phenomena, Lorentz Transformations of Electromagnetic Fields |
| **15** | DG | Construction of Electromagnetic Field Tensor, Covariant Form |

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| | 12.3.3 | of Maxwell Equations |
| | 12.3.4 | |
| **16** | DG 12.3.5 | Relativistic Potentials, Gauge Transformation of Electromagnetic Field |